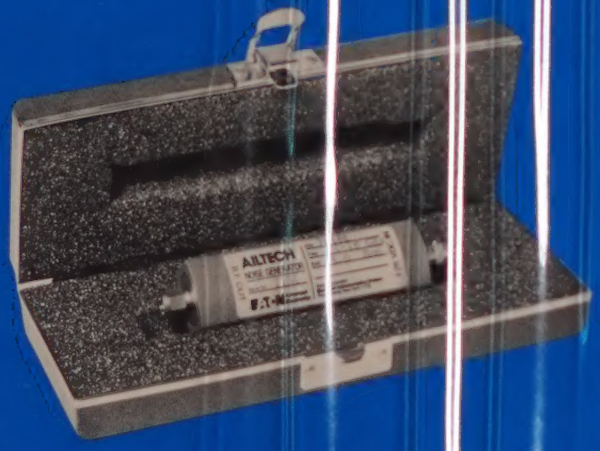
Ailtech

TOPICS IN NOISE



E·A·T·N

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Technical Data
2075 Noise-Gain Analyzer

NEW!

Ailtech

A Microprocessor Based, Computer Compatible Instrument

IEEE 488 GPIB

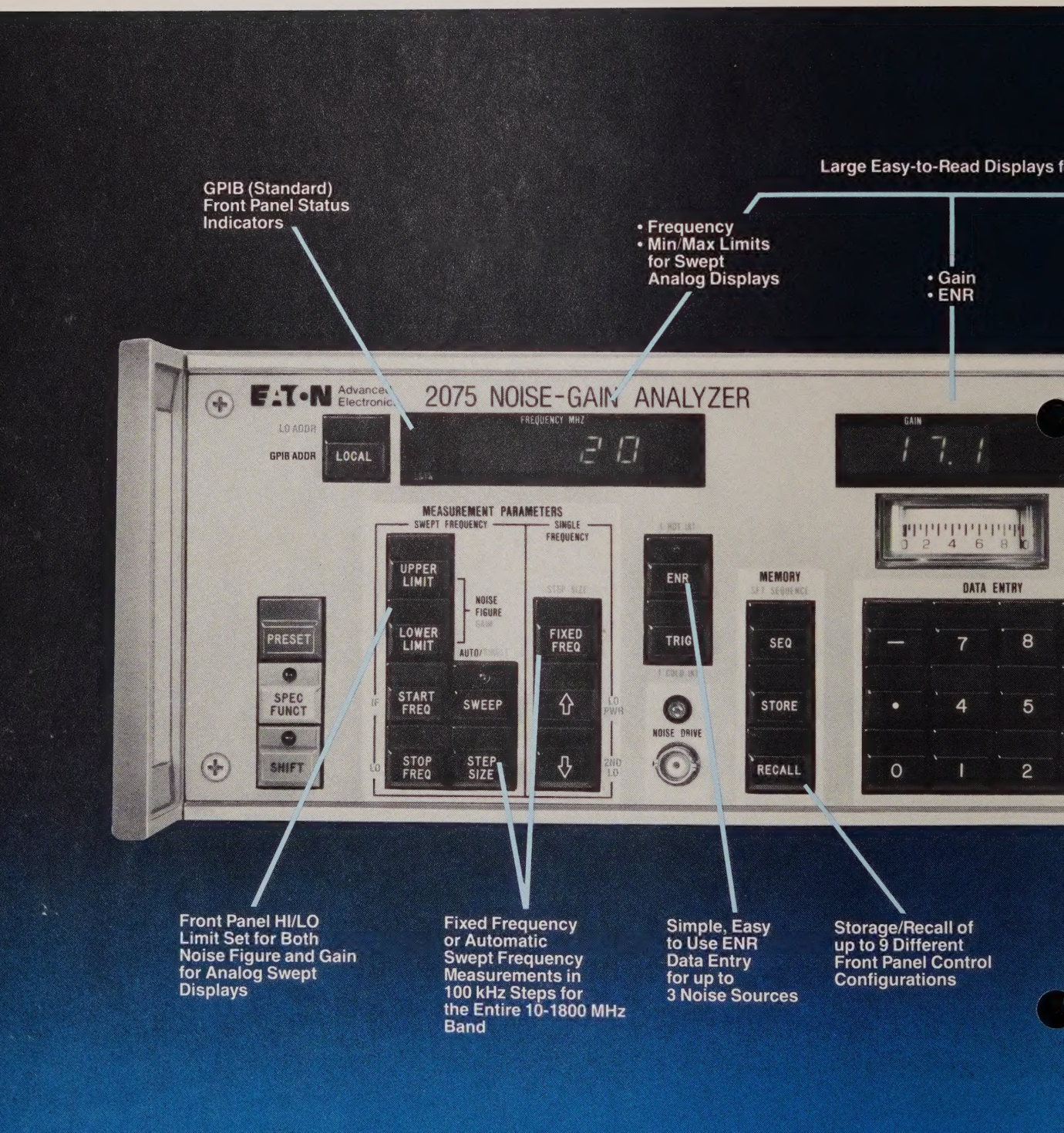
Noise Figure and Gain Measurements made:

- Simple
- Convenient
- Over Wide Frequency Ranges

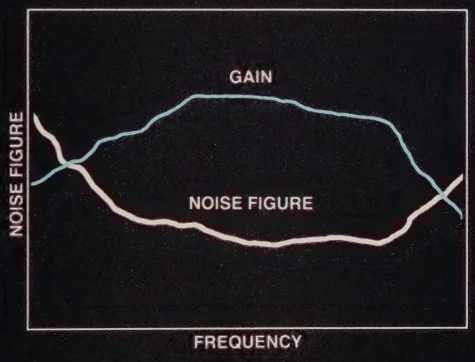
...with Outstanding Accuracy, Resolution and Precision

E·A·T·N

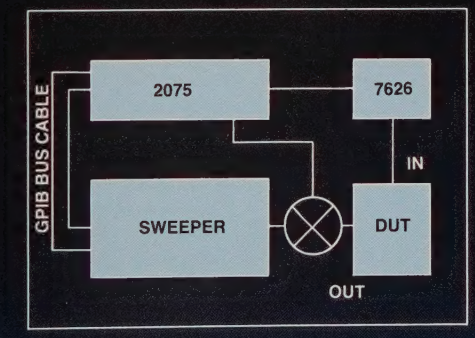
2075-2 10 to 1800 MHz (Tunable) Noise-Gain Analyzer.



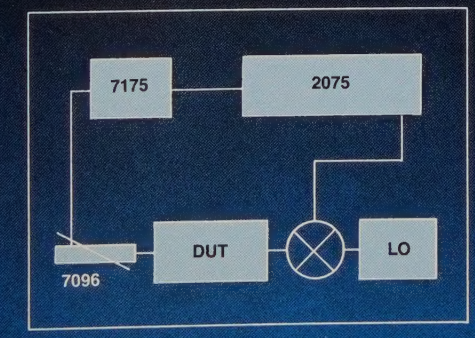
Measure • Noise Figure • Effective Input Noise Temperature • Gain • Noise Measure from 10 MHz to 40 GHz



10 MHz to 1800 MHz requires no additional preamplifiers, mixers, or accessories. A typical scope display is illustrated showing simultaneous readout of noise figure and gain vs. frequency. When using an AILTECH 2075 Noise-Gain Analyzer for measurements in the 10 to 1800 MHz range, other than a noise generator, no external equipment is required. The rear panel makes available analog X-Y outputs that are compatible with most standard laboratory oscilloscopes and recorders. In addition there is a Z axis output, which can be used for blanking the oscilloscope or as a pen lift on a recorder.



Swept Microwave Measurements with an external local oscillator. The block diagram shows the set-up that can be used to make measurements anywhere from 1800 MHz to 26 GHz with an appropriate bus programmable local oscillator. The AILTECH 2075 Noise-Gain Analyzer sends frequency commands over the interface bus to tune the local oscillator across the band of interest. This eliminates the need for a desk top computer or external controller for error corrected swept microwave measurements. All of the correct addressing and data formatting is provided by the AILTECH 2075. The basic instrument will include the ability to control three specific industry-standard local oscillators. This feature is extremely valuable in testing broadband microwave amplifiers, mixers, and devices since, in addition to saving the cost of utilization of the computer, it eliminates a great deal of the programming or software effort that the computer will generally require.



Measurement Capability up to 40 GHz, Exclusive with AILTECH Instrumentation! If your tests require measurements from 100 MHz to 26 GHz, the AILTECH 7626 solid state noise generator is the solution.
From 26 GHz to 40 GHz, where you must use a waveguide gas discharge noise generator, the AILTECH instrumentation team of a remotely triggerable 7175 gas discharge noise generator Power Supply, a 2075 Noise-Gain Analyzer and a 7096 gas discharge Noise Generator provide the measurement capability with a compatible noise figure measurements system.

2075 Noise-Gain Analyzer Specifications

NOISE MEASUREMENT

Noise Figure Range	0 to 30 dB
Measurement Accuracy	±.05 dB A) 0 to 12 dB Noise Figure B) +10 to +40°C C) ENR 5 to 18 dB ±0.1 dB A) 12 to 30 dB Noise Figure B) T < 10°C, > 40°C
Resolution	.01 dB

Measurement accuracy specifications are valid for uncorrected noise figure over the full gain measurement range of the instrument.

GAIN MEASUREMENT

Gain Range	−20 to > 50 dB
Measurement Accuracy	±0.2 dB
Resolution	.01 dB

INPUT

Frequency Range	10 to 1800 MHz, tunable
Tuning Accuracy	±(0.5 MHz + 0.005F), ±3 MHz Max
Frequency Resolution	0.1 MHz
Noise Figure	< 7dB + 0.002 dB/MHz A) Input Level < −40 dBm
Input VSWR	< 1.5
Maximum Input Power	+20 dBm
Maximum Net External Gain	>75 dB

EMC–ELECTROMAGNETIC CAPABILITY

EMI	MIL-STD-461 CE03,RE02 CISPR Pub 11 (1975) VDE
EMS	MIL-STD-461 CS01, CS02, CS06, RS03, (1 V/M)

GENERAL

Noise Source Drive (ON)	+28 ± .05V, up to 100 ma Available
(OFF)	< 1 V
Operating Temperature	0 to 55°C
Storage Temperature	−55 to 75°C
Power	100, 120, 220 or 240 V (±10%) 48-66 Hz; 150 VA Max.
Weight	34 lb., (15.5 kg)
Dimensions	5¾″ x 16⅞″ x 14″, (14.6 x 42.86 x 35.56 CM) (5¼″, 13.33 cm rack panel space)

SUPPLEMENTAL CHARACTERISTICS

Bandwidth	5 MHz (nominal)
Measurement Speed	6 to 10 meas/sec
Maximum Safe Input Level	±20 Vdc; + 25 dBm RF

FUNCTIONS & FEATURES

Noise Figure Display	F dB F Y dB* Y* Te (K)* M* Top (K)* dB PWR* Default display is FdB. *require SP function. All others are front panel control. Return from SP function is front panel control. dB/ Ratio selection for F or Y is a front panel toggle.
Controller Functions	Wiltron 6600 HP 8672 A HP 8350 A General Format Digital Printer (Listen Only) 2075 (Talk Only)
ENR Storage Capacity	3 sets @ 31 frequencies 1 ROM input (4 total)
Analog Display Set-up	F & G min-max, front panel
External Relay Drive	5, 15 or 30 V, Operator selected by internal jumper
Programmability	IEEE-std.-488-1978

ACCESSORIES

7615 10 MHz to 1500 MHz solid-state Noise Generator

7616 1 GHz to 12.4 GHz solid state Noise Generator

7617 12.4 to 18 GHz solid state Noise Generator

7618 1 GHz to 18 GHz solid state Noise Generator

7618E 10 MHz to 18 GHz solid state Noise Generator

7626 10 MHz to 26.5 GHz solid state Noise Generator

7175 gas discharge noise generator Power Supply

70 series 8.2 to 40 GHz waveguide gas-discharge Noise Generators

Specifications subject to change without notice.

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Electronic Instrumentation Division
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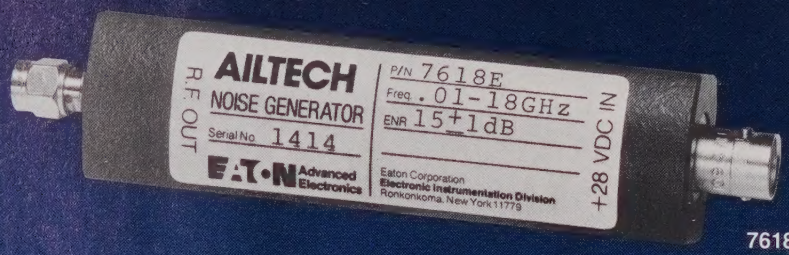
Telephone: (516) 588-3600
Telex: (510) 228-6507

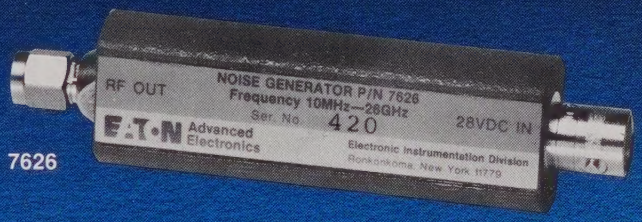
EATON

Ailtech

Solid State Noise Generators
7618E 10MHz to 18GHz
7626 10MHz to 26GHz



7618E



7626

ACTUAL SIZE

A Major Improvement in Cost Effectiveness and Measurement Convenience in Noise Figure Measurement Systems

EATON

Cost Effective
Convenient
Accurate
Precise

Cost Effective

10MHz to 26GHz in a single, precise, accurate, solid-state noise generator (18GHz for the 7618E). If your noise figure measurement needs cover several traditional frequency bands, you can save thousands of dollars over past conventional solid-state offerings with one of these broadband generators.

Moreover, if your application extends above 18GHz (the traditional upper limit of laboratory solid-state noise generators), you can dispense with fragile, gas-discharge, waveguide noise sources and their expensive, high voltage power supplies.

Convenient

Regardless of whether your application is component or subassembly testing (amplifiers, mixers, transistors, GaAsFETSs, etc.) or measurement of complete receiver systems, the 7618E or 7626 is probably the only noise generator you will ever need.

Consider, for example, the measurement problems associated with a modern, satellite communications system with an intermediate frequency of 140MHz, an up link frequency in the 15 to 18GHz band and a down link frequency in the 19 to 21GHz band. In the past, one solid-state noise generator would be required for the I.F. measurement, another for the up link, and a waveguide, gas-discharge generator (probably with accuracy-degrading waveguide to coaxial adapters) for the down link measurements. In addition, the gas-discharge noise generator, besides being cumbersome and rather fragile, requires a special power source.

A single, AILTECH 7626 is the only noise generator required for this application. Moreover, the 7626, with its precision, male SMA output connector, eliminates the need for adapters in most cases.

Accurate

±0.25 dB *WORST CASE* uncertainty at 18GHz. EATON always quotes worst case; thus, you, the user, can have absolute confidence that your measurements are within a specific range rather than the uncertainty of wondering whether or not your particular noise generator is actually outside its root-sum-squares specified tolerance.

An absolute knowledge of noise generator excess noise ratio (ENR) tolerance can save you hours tracking down measurement error sources and correlation discrepancies between engineering and production test, incoming inspection, and vendor, etc.

Every AILTECH noise generator is calibrated using the AILTECH Model 82 Noise Calibration System.* At applicable frequencies, the calibration of EATON's noise standards is directly traceable to the National Bureau of Standards (NBS). At other frequencies, calibration is traceable to the Electronic Quality Assurance Directorate, Aguila, Bromley, England, and cross-checked against thermal noise standards.

The worst-case, excess noise ratio (ENR) uncertainties at each calibration frequency are tabulated under "Specifications" of this brochure on the last page. The uncertainties listed are standard production values. At some frequencies, EATON can provide a precision calibration (at additional cost) and offer even better accuracy (e.g.: ±0.15dB at 18GHz). Consult the factory for details.

and More

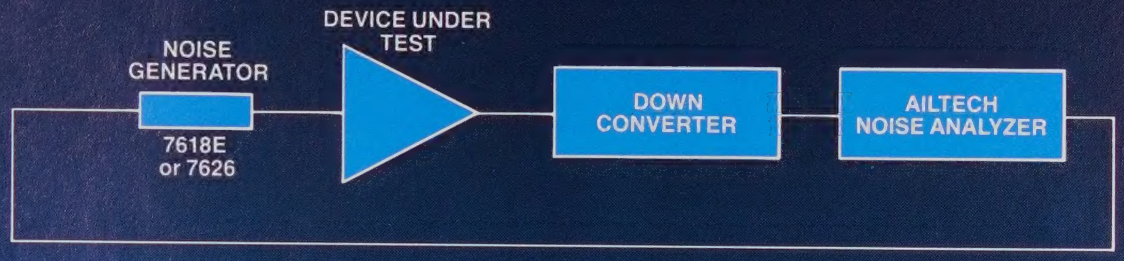
The unusually broad frequency coverage of the 7618E and the 7626 results in time and money savings, but the major characteristic of a noise generator is accuracy.

An analysis of a noise figure measurement set-up will show that noise generator accuracy is the major contributor to the overall measurement uncertainty. Recognizing this, EATON provides ENR calibration points every GHz above 1GHz as well as at 30, 100, 300 and 1500MHz. The worst-case calibration accuracies of the 7618E and the 7626 are shown in table A.

The accuracy of a noise figure measurement using standard techniques (see figure 1 for an illustration of a typical set-up) can also be affected by the source mismatch seen by the input of the device-under-test. The noise figure of a device can change if the source impedance varies. Since the noise generator assumes two conditions during the measurement (on and off), this could add a further uncertainty to the results. The low SWR of AILTECH noise generators in both the on and off condition reduces this uncertainty, further improving measurement accuracy. Maintaining a low SWR is important because source mismatch effects on noise figure measurement accuracy have never been completely analyzed. The excellent mismatch performance of the 7618E and 7626 are illustrated in figures 2, 3 and 4.

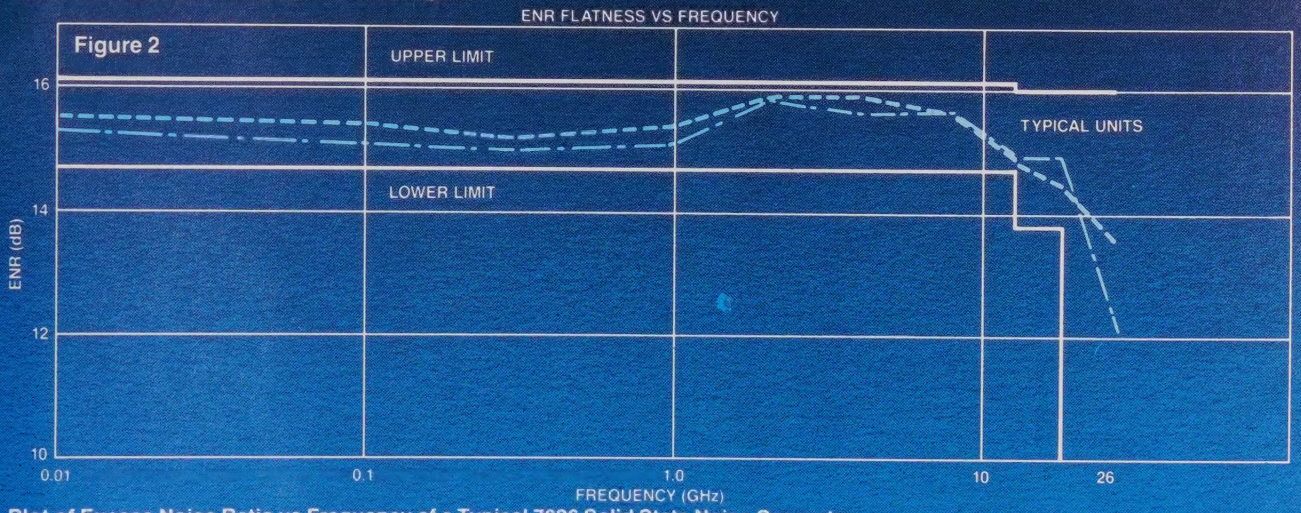
*This system was reviewed by the National Bureau of Standards in 1968 (NBS Report #9729 "Error Analysis of the AIL Noise Measuring System," W. C. Daywitt, Sept. 1968). Copies of this report are available from EATON Corporation, Electronic Instrumentation Division, upon request.

Figure 1



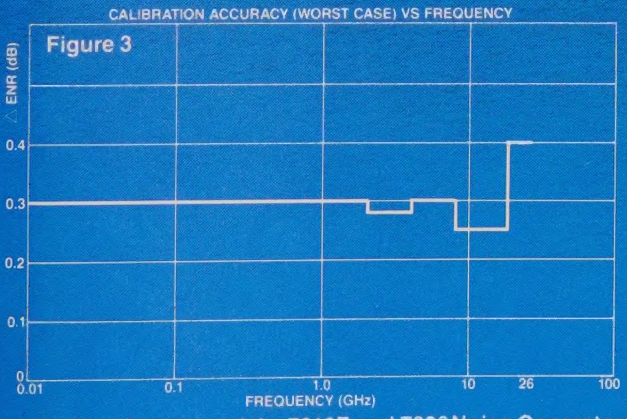
Typical Setup Used to Measure Noise Figure

Figure 2



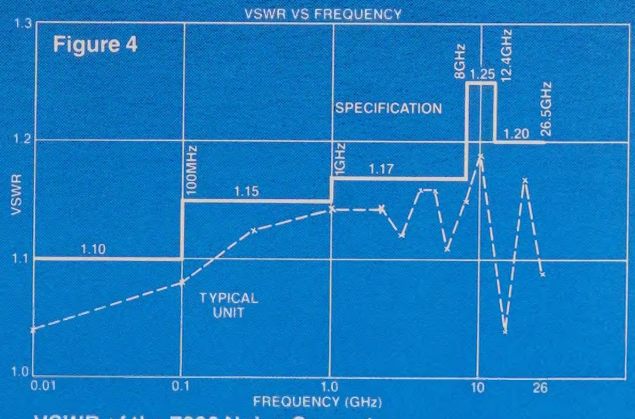
Plot of Excess Noise Ratio vs Frequency of a Typical 7626 Solid State Noise Generator

Figure 3



Calibration Accuracy of the 7618E and 7626 Noise Generators

Figure 4



VSWR of the 7626 Noise Generator

Specifications

Frequency Range:
7618E 10MHz to 18GHz
7626 10MHz to 26.5GHz

Excess Noise Ratio (ENR):
7618E 15.0dB nominal
7626
10MHz to 12.4GHz
15.4dB nominal
12.4 to 18GHz
14.9dB nominal
18 to 26.5GHz
13.0dB nominal

ENR Flatness with Frequency:
7618E ±1dB
7626
10MHz to 12.4GHz, ±0.7dB
12.4GHz to 18.0GHz, ±1.1dB
18.0GHz to 26.5GHz, ±3.0dB

SWR (maximum) ON or OFF:
7618E
10MHz to 4.0GHz,1.20
4.0GHz to 12.4GHz,1.25
12.4GHz to 18.0GHz,1.30
7626
10MHz to 100MHz,1.10
100MHz to 1.0GHz,1.15
1.0GHz to 8.0GHz,1.17
8.0GHz to 12.4GHz,1.25
12.4GHz to 26.5GHz,1.20

Connectors:
Input, BNC female
Output, Precision SMA male

Power Required:
+28 volts @ <20ma.

Maximum Reverse RF Power:
1 watt

Size:
7618E .....4¼", 10.79 cm.
7626 .....3½", 8.89 cm.

Weight:
7618E ..... 3 oz., 85 gr.
7626 ..... 2 oz., 56.7 gr.

Table A
ENR Accuracy:

Frequency (GHz)	Worst Case Uncertainty (dB)	Traceability*	Frequency (GHz)	Worst Case Uncertainty (dB)	Traceability*
0.03	0.30	EQD	13.0	0.25	NBS
0.3	0.30	EQD	14.0	0.25	NBS
1.0	0.30	EQD	15.0	0.25	NBS
2.0	0.30	EQD	16.0	0.25	NBS
3.0	0.28	NBS	17.0	0.25	NBS
4.0	0.28	NBS	18.0	0.25	NBS
5.0	0.30	H/C	19.0	0.40	G
6.0	0.30	EQD	20.0	0.40	G
7.0	0.30	EQD	21.0	0.40	G
8.2	0.25	NBS	22.0	0.40	G
9.0	0.25	NBS	23.0	0.40	G
10.0	0.25	NBS	24.0	0.40	G
11.0	0.25	NBS	25.0	0.40	G
12.0	0.25	NBS	26.0	0.40	G

*EQD: Electronic Quality Assurance Directorate
H/C: Thermal Noise Standard
NBS: U.S. National Bureau of Standards
G: Internal Gas Standard

In the interest of product improvement, specifications are subject to change without notice.

Supplemental Characteristics

ENR Variation with Temperature:
<0.01dB/°C

ENR Variation with Voltage:
<0.1dB/%△V

Switching Speed:
<2μs

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EATON

AILTECH Noise Figure Instrumentation
AILTECH System Noise Monitors

EATON Advanced Electronics

Complete Instrumentation for Noise Figure Measurement and Calibration

The noise generated within the subassemblies and components of a receiver system is an inherent limitation on the ability of the receiver to extract information from a remotely located source — with or without the cooperation of that source. Thus, this limitation applies to virtually all electronic segments utilizing receiver technology: communications, radar, ECM, ELINT, telemetry, etc.

The concept of noise figure is a means of characterizing these basic limitations. It is recognized by the designers and manufacturers of subsystems, modules, and components of receiver systems. Thus, the designer has an established common language that can be used to transpose sensitivity requirements into unambiguous, accurately measurable specifications for all elements of the system from the most complex subsystem to the smallest active device.

In the specialized field of noise measurement technology requiring specialized instruments, Eaton Corporation, Electronic Instrumentation Division's (EID) origin places it in the unique position of being closely attuned to user needs. EID's acknowledged leadership in receiver noise measurement technology is a direct result of its outgrowth from a company well known for sophisticated low noise receivers and has led to the development of a complete line of instruments and accessories applicable to all levels and segments of receiver technology.

The AILTECH noise measurement equipment described in this brochure consists of:

A "laboratory" line featuring the highest degree of accuracy and versatility offered by EID. These instruments and accessories provide for precise direct reading measurements (AILTECH 7514 Precision Automatic Noise Figure Indicator — PANFI), and the means for accurate manual Y-factor measurements (AILTECH 13611 Precision Test Receiver — PTR).

System Noise Monitors (SNM) offering Simplicity and Economy for field, on-line monitoring and production applications. These instruments (AILTECH 7300 Series) feature ease-of-use, on-line measurement capability, IEEE-STD-488 Interface compatibility, and, in one unit (7380), simultaneous noise figure and gain measurements.

Noise generators, gas-discharge and solid-state, compatible with both general classes of instruments outlined above, covering 10 MHz to 40 GHz and calibrated with traceability to the National Bureau of Standards, where applicable.

The only commercially available system designed specifically for the calibration of R.F. and microwave noise generators.

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An Introduction to Noise Figure Measurement

Basic Considerations

Noise in amplifiers and receiving systems is usually expressed in terms of an equivalent thermal noise source; i.e., the noise power available from a resistive termination in a fixed thermal environment. Thus,

$$P_{AV} = kTB$$

where, k = Boltzmann's Constant (1.38×10^{-23} joules/kelvin)

T = absolute temperature (kelvins)

B = noise bandwidth (hertz)

Noise Figure can be defined as the ratio of the actual noise power output of a transducer (receiver or amplifier) to that of an ideal, noiseless transducer of otherwise identical characteristics, when the source termination is at the standard reference temperature, T_o (290K).

$$F = \frac{N_{Actual}}{N_{Ideal}} = \frac{N_{s_o} + N_i}{N_{s_o}}$$

where, N_{s_o} = noise power available from the source termination at 290K

N_i = noise power generated within the transducer referred to the input port

Since, $N_{s_o} = kT_oB$

then, $N_i = k(F-1)\,T_oB$

leading to the general transducer noise model shown in Figure 1.

Measurement Technique

The general noise figure measurement procedure consists of successively applying two known source termination conditions (T_H, T_C) at the input of the device-under-test (DUT), and measuring the **ratio** of the resulting noise powers at the DUT output. This output ratio is commonly called the Y-factor; thus,

$$Y = \frac{T_H + (F-1)T_o}{T_C + (F-1)T_o}$$

and Noise Figure, expressed as a ratio, can be calculated from:

$$F = \frac{\frac{T_H}{T_o} - Y\,\frac{T_C}{T_o}}{Y-1} + 1$$

This equation should be used when the cold source temperature (T_C) differs from the Standard Reference Temperature (T_o) — a situation that occurs when the AILTECH 7009 Hot-Cold Standard Noise Generator (page 21) is used.

In most laboratory and system monitoring applications, the cold source temperature is room temperature (provided by the simple expedient of turning the noise generator off) and is assumed equal to T_o (290K); then,

$$F = \frac{\frac{T_H}{T_o} - 1}{Y-1}$$

The quantity in the numerator, a function of the noise generator output, is commonly called excess noise ratio (ENR), and is usually expressed in dB; therefore,

$$F_{dB} = ENR_{dB} - 10LOG_{10}(Y-1)$$

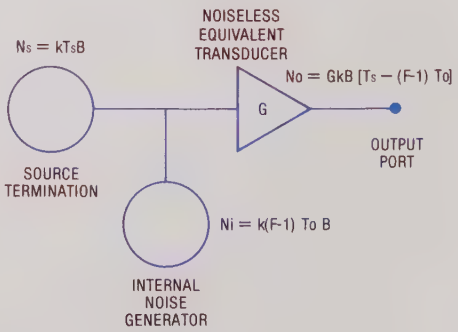


FIGURE 1

GENERAL TRANSDUCER NOISE MODEL

General Laboratory Applications

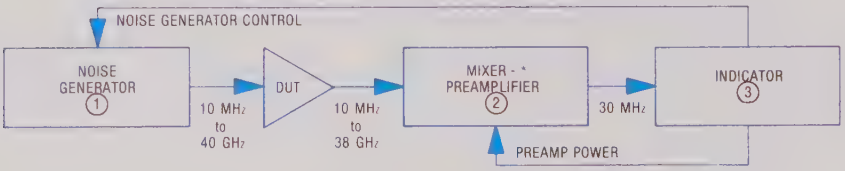
The Y-factor can be measured by series I.F. substitution, and Noise Figure calculated by means of the equations on the preceding page. This is referred to as the Manual Y-factor technique and is generally used when the need for accuracy outweighs the convenience of direct-reading instrumentation. The AILTECH 13611 Precision Test Receiver or an AILTECH 32 Precision Attenuator in conjunction with the 7514 PANFI provide the basic means for implementing this measurement method.

Alternatively, considerable cost-savings and convenience can be achieved by direct-reading instruments such as the AILTECH 7514 or 7300 Series System Noise Monitors. These are I.F. receivers that implement the Y-factor measurement by switching the noise generator on and off, measuring the Y-factor, and displaying the results as Noise Figure.

These instruments operate at intermediate frequencies as a means of optimizing the combination of accuracy, measurement dynamic range, and ease of operation. The following block diagrams illustrate typical measurement set-ups for both direct-reading and manual measurements.

Additional applications information relating specifically to System Noise Monitors will be found on page 12.

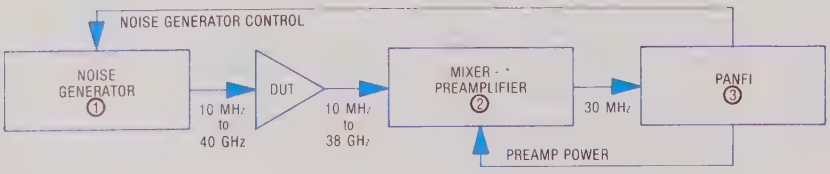
FIGURE C TYPICAL MANUAL SET-UP



* Not required if DUT output is at 30 MHz & > − 70 dBM

1. 7600 SERIES OR 7175 POWER SUPPLY +70 SERIES (PAGE 21)
2. 135/136 (PAGE 10-11)
3. 13611 (PAGE 8-9) OR 7514 +32 SERIES (PAGE 6-7, 11)

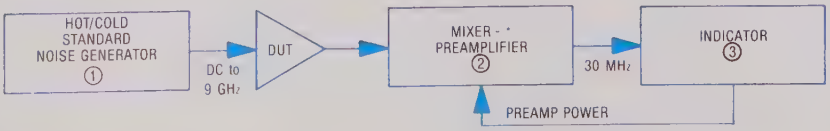
FIGURE D TYPICAL DIRECT READING SET-UP



* Not required if DUT output is > − 80 dBM @ 30 MHz. See 7514-09 for other I.F.'s.

1. 7600 SERIES OR 7175 — 70 SERIES (PAGE 21)
2. 135/136 (PAGE 10-11)
3. 7514 (PAGE 6-7)

FIGURE E HIGH ACCURACY MANUAL SET-UP



* Not required if DUT output is at 30 MHz & > − 70 dBM.

1. 7009 (PAGE 20)
2. 135/136 (PAGE 10-11)
3. 13611 (PAGE 8-9) OR 7514 + 32 SERIES (PAGE 6-7, 11)

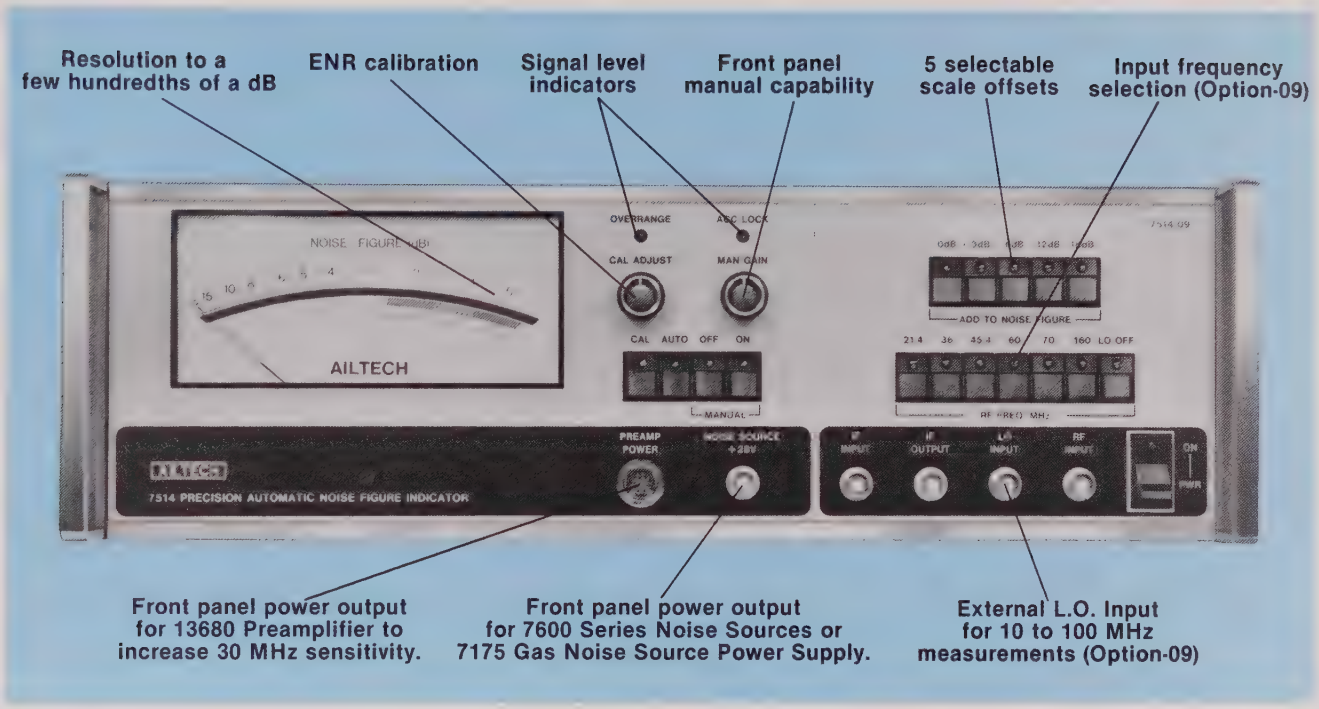
7514 Precision Automatic Noise Figure Indicator

The AILTECH 7514 is the latest in Eaton Corporation's line of highly accurate, direct-reading noise figure instruments. This new instrument provides the means to accurately and easily measure the noise figure of an amplifier or receiver. Its fast, direct-reading capability offers the user the means to immediately evaluate the effects of circuit adjustments on noise performance.

With its wide dynamic range, signal strength indicators, ENR calibration, and frequency versatility (with the –09 Option), the AILTECH 7514 relieves the user of many tedious set-up calculations and tasks and generally simplifies the measurement to a one-step operation.

Among the features offered by the 7514 are:

Accuracy	Typically to ±0.05 dB (exclusive of noise source) at low noise figures.
Resolution	Provided by a large, easy-to-read expanded meter scale that spreads a 3 dB range over one-half the meter arc enabling resolution to a few hundredths of a dB.
Range	Six, switch-selectable offsets provide full-scale ranges of 0, 3, 6, 12, and 18 dB, with extension to infinity on each range; thus, providing readability to 33 dB and preserving the high resolution for most noise figure measurements.
ENR Calibration	Provided by a patented calibration system, operated from the front panel, that permits the user to scale the instrument to be direct-reading for a range of noise generator outputs (excess noise ratio).
Dynamic Range	The 7514 will provide accurate measurements over an input signal level window of better than 65 dB.
Level Indicators	Two front panel, LED indicators marked "AGC" and "OVERRANGE" provide the operator with a positive indication that the input signal is within the instrument's dynamic range.
RF Range	The AILTECH 7514 will drive all AILTECH 7600 Series Solid-State Noise Generators; thus, it is a valuable tool for measuring the noise performance of amplifiers and receiving systems from 10 MHz to 18 GHz — but, with the addition of the 7175 Power Supply and 70 Series Noise Generators (page 21), this range is extended to 40 GHz.
Frequency Versatility	With the optional Frequency Converter (Option-09), the 7514 provides for six, preselected input frequencies in addition to 30 MHz. As an added capability, the Converter Option provides an input for an external local oscillator enabling operation from 10 to 1000 MHz.
Status Indicators	LED indicators on all front panel switches, provide the operator with a visual indication of operating mode, range selected, etc.


Resolution to a few hundredths of a dB
ENR calibration
Signal level indicators
Front panel manual capability
5 selectable scale offsets
Input frequency selection (Option-09)
NOISE FIGURE (dB)
AILTECH
OVERRANGE
ARC LOCK
CAL ADJUST
MAN GAIN
CAL AUTO OFF ON
MANUAL
ADD TO NOISE FIGURE
21.4 30 45.4 60 70 160 LO OFF
RF FREQ MHz
PREAMP POWER
NOISE SOURCE +28V
7514 PRECISION AUTOMATIC NOISE FIGURE INDICATOR
IF INPUT
IF OUTPUT
LO INPUT
RF INPUT
ON
PWR
Front panel power output for 13680 Preamplifier to increase 30 MHz sensitivity.
Front panel power output for 7600 Series Noise Sources or 7175 Gas Noise Source Power Supply.
External L.O. Input for 10 to 100 MHz measurements (Option-09)

Specifications

Input Frequency
7514 — 30 MHz

7514-09 — 21.4, 30, 36, 45, 60, 70, 160 MHz, front panel switch selectable except for 30 MHz (patch cable required). 10 to 1000 MHz with an external local oscillator.

Accuracy
Typical (at constant temperature and input level) — ±0.05 dB +0.05 dB per 3 dB increment

Guaranteed — ±0.1 dB, 0 to 9 dB, ±0.2 dB, ±0.4 dB, 12 to 18 dB, ±0.75 dB, 18 to 21 dB, ±1.0 dB, 21 to 30 dB (usable to 33 dB)

*Exclusive of noise source accuracy

Sensitivity
30 MHz — –80 dBm (nominal)

Option -09 — –72 dBm (nominal

Input Level Range
65 dB (minimum)

ENR Calibration Range
14.0 to 16.5 dB

Noise Source Output
+28volts CW or modulated; sufficient to drive all AILTECH 7600 Series Solid-State Noise Generators and the 7175 Power Supply

Supplemental Characteristics

Bandwidth
30 MHz — 6 MHz nominal

Option -09, except 30 MHz — 3 MHz nominal

Preamplifier Power Output
Provides power for a 13680 Preamplifier (page 10-11) to increase sensitivity

Recorder Output
50 mV (nominal) at full deflection, 5 KΩ balanced

Size
5-1/4" H x 17" W x 14-7/8" L (13.3 x 43.2 x 37.8 cm)

Weight
21 lbs. (9.5 kg) net. 30 lbs. (13.6 kg) ship.

Line Power
115/230 V ±10%, 50 to 400 Hz, 35 watts (nominal)

Options

Frequency Converter Option -09
Rack Mount Brackets Option -11

Accessories

Solid-State Noise Generators 10 MHz to 18 GHz, AILTECH 7600 Series (page 20)

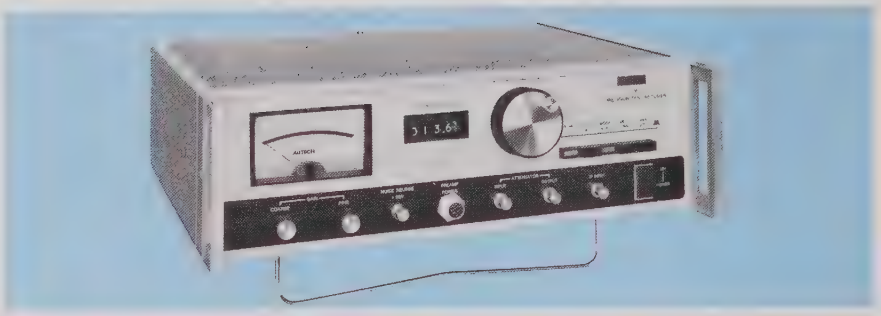
Gas-Discharge Noise Generator Power Supply, AILTECH 7175 (page 21)

Gas-Discharge Noise Generators to 40 GHz, AILTECH 70 Series (page 21)

Mixer-Preamplifiers, AILTECH 135/136 Series (page 10-11)

Low Pass Filter, AILTECH 230434 (for measurements on devices with high level spurious outputs, such as television tuners)

13611 Precision Test Receiver



This 30 MHz test receiver is a valuable, general-purpose, laboratory test tool which can be used for many applications requiring accurate, precise measurement of power level changes over the frequency range from 10 MHz to 38 GHz. This includes:

- Receiver/amplifier noise parameter measurements
- Attenuation or insertion loss measurements
- Gain measurements
- Signal generator output level calibration
- Differential mode power meter calibration

The AILTECH 13611 Precision Test Receiver is designed specifically for series-substitution measurements. In the series-substitution method, an RF signal is linearly down-converted by an external mixer-preamplifier (see pages 10-11) to the Receiver intermediate frequency (IF), 30 MHz. Any change in the RF power level is measured by adding, or removing, an equal amount of IF attenuation by means of the Precision Variable Attenuator within the Receiver. The instrument is compatible with all AILTECH 135/136 Series Mixers and Preamplifiers. These accessories provide the means for operation over the frequency range from 10 MHz to 38 GHz.

A major application of the Precision Test Receiver is measurement of receiver and amplifier noise performance parameters via the classic manual Y-factor method (see facing page). The combination of an AILTECH 7009 Hot/Cold Standard Noise Generator and a 13611 Precision Test Receiver has the capability of measuring noise figure to better than ±0.1 dB.

A new feature has been added to the AILTECH 13611 to facilitate Y-factor measurements when using typical, commercially-available, solid-state noise sources (such as the AILTECH 7600 Series). The receiver incorporates a highly-stable, regulated, +28 volt D.C. power supply required by such sources. On-off control and the output connection is at the Receiver front panel; thus, the instrument provides all the functions necessary for the measurement — both noise source power and Y-factor measurement capability.

Depending upon frequency and external local oscillator stability, the AILTECH 13611 can measure loss or gain up to 60 dB at R.F. and 100 dB at 30 MHz with a resolution of 0.01 dB. Accuracy is a function of the measured range and is primarily determined by the built-in, waveguide-beyond-cutoff, continuously variable attenuator (see specifications on facing page).

The receiver consists of a Precision Attenuator, whose input and output connections are brought out to the front panel (for use exclusive of the Receiver), a high-gain 30 MHz postamplifier with manual coarse and fine gain controls, an integral linear detector, and a meter circuit with switch-selectable expansion. The meter circuit can also be switched into the external crystal monitor lines for measurement of crystal currents in AILTECH 135 Series mixers — a valuable aid in setting up for microwave measurement.

Specifications

Input Frequency	30 MHz
Input Impedance	50 ohms nominal
Full-Scale Sensitivity (Note 1)	−90 dBm
Attenuator	
Range, incremental	100 dB minimum
Accuracy, incremental	0.005 dB/10 + 0.03 dB (Note 2)

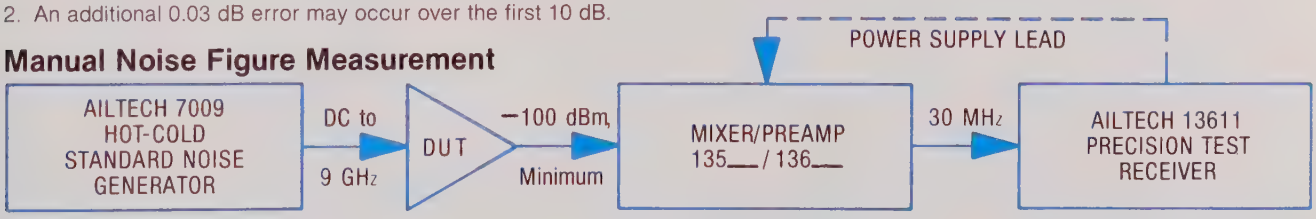
Supplemental Characteristics

Bandwidth	1 MHz (nominal)
System Measurement Range & Accuracy	
IF (30 MHz)	100 dB ± 0.4 dB
RF (10 MHz to 38 GHz)	60 dB ± 0.3 dB
Gain-Control Range	45 dB (minimum)
Scale Resolution	Normal 0.05 dB, expanded 0.005 dB (1/2 minor scale division)
Video Output	0.5 volt (100-ohm load, nominal)
IF Output	100 mV (50-ohm load, nominal)
Noise Source Output	+28 volts, sufficient to drive all AILTECH 7600 Series Solid-State Noise Generators and the 7175 Gas Noise Generator Power Supply
Line Power	115/230 V ±10%, 50 to 400 Hz, 20 Watts (nominal)
Size	5-1/4" H x 17" W x 14-7/8" L (13.3 x 43.2 x 37.8 cm)
Weight	32 lbs. (14.5 kg) net 41 lbs. (18.6 kg) shipped
Rack Mounting	Requires optional rack mount brackets (Option 11)

Notes

1. Available signal power at Postamplifier input, which will cause the meter to read full-scale or greater.
2. An additional 0.03 dB error may occur over the first 10 dB.

Manual Noise Figure Measurement



For the greatest accuracy in noise figure measurement, the Manual method should be used. This method eliminates tracking inaccuracies and non-linearities associated with detection systems. When the 13611 Precision Test Receiver is used with the 7009 Hot-Cold Standard Noise Generator, it is possible to measure noise figure to accuracies of better than ±0.1 dB. A typical setup is illustrated in the following block diagram.

In the "manual Y-factor" method, two terminations at known temperatures are alternately connected to the input of the device/system under test. The change in the output noise-power level is noted (called the Y-factor). Effective, input noise temperature (T_e) or noise figure (F) is calculated from

$$T_e = \frac{T_2 - YT_1}{Y-1} \quad \text{and}$$

$$F = \frac{\frac{T_2}{T_o} - Y\frac{T_1}{T_o}}{Y-1} + 1$$

where T_2 and T_1 are the "hot" and "cold" source termination temperatures in Kelvins, respectively.

Accessories for use with Noise-Figure Instrumentation

13680 Preamplifier with coaxial mixer

13681 Preamplifier with waveguide mixer

13680 Preamplifier with converter

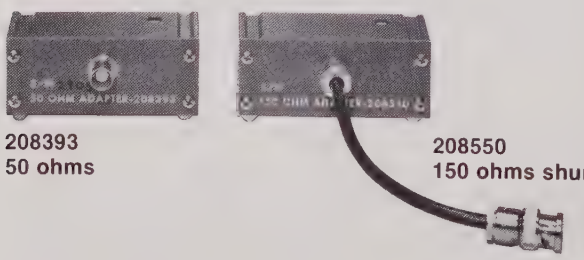
Mixers and Frequency Converters

The AILTECH 135-series Mixers, and 13635 Frequency Converter, effectively extend the frequency range of the 7514 PANFI and 13611 Precision Test Receiver to cover the entire 0.01-38 GHz spectrum. The individual Mixers and Converter plug directly into any of the AILTECH 136-series Preamplifiers. The combination of mixer-preamplifier, or converter-preamplifier, converts an entire RF band into the high-level, 30 MHz-output necessary to drive the AILTECH 7514 or 13611.

Part Number	Frequency Range (GHz)	Connector Type	L.O. Level (nominal)
13635	0.04-0.15	Type N	Internal, tuneable L.O.
13508	0.01-1	TNC	5mw (+7 dBm)
13504	1 -2	TNC	5mw
13505	2 -4	Type N	1mw (0 dBm)
13506	4 -8	Type N	1mw
13507	7 -11	Type N	1mw
13509	3.6 -4.2	Type N	1mw
13546	8.2 -12.4	WR-90	1mw
13547	12.4 -18.0	WR-62	1mw
13553	18.0 -26.5	WR-42	1mw
13596	26.5 -38	WR-28	1mw

Impedance Adapters

Plug-in Adapters are available to impedance-match the 136-series Preamplifiers to source impedances of 50 ohms or 150 ohms — 15 pf (a typical balanced-mixer output impedance).



208393
50 ohms

208550
150 ohms shunted by 15 pf

136 Series Preamplifiers

Preamplifiers

AILTECH 136-series preamplifiers will accept any of the AILTECH 135-series "plug-in" Mixers, or 13635 Frequency Converter, or AILTECH 208-series Adapters. The Preamplifiers are powered directly by the 7514 PANFI or 13611 Precision Test Receiver.

The AILTECH 13680 is the preferred choice when the noise figure of the Measurement System itself must be a minimum.

The AILTECH 13681 has a linear dynamic range in excess of 80 dB on CW signals and 70 dB on noise. In conjunction with the 13611 Precision Test Receiver, it is particularly well suited for measurement of large attenuation values. Moreover, the 13681 Preamplifier will not limit the 65-dB dynamic range of the AILTECH 7514 PANFI.

Specifications

Part Number	**13680**	**13681**
Center Frequency	30 MHz	30 MHz
Bandwidth (minimum)	3 MHz	3 MHz
Gain (minimum)	45 dB	30 dB
Noise figure (nominal)	3.3 dB	6 dB
Maximum linear output (0.1 dB compression)	+17 dBm	+17 dBm
Maximum output power (nominal) (50 ohm load)	+27dBm	+27 dBm
Power Required	20 vdc at 225 mA	20 vdc at 225 mA

Cased Precision Attenuator

Precision Attenuators

The AILTECH 32-series Precision Attenuators are identical to the attenuators incorporated in the 13611 Precision Test Receiver and 8210 Noise Temperature Calibrator. The Attenuators are used to make accurate, Manual, Y-factor measurements in conjunction with the AILTECH 7514 PANFI. Moreover, the attenuators may be used as secondary-standards in attenuation calibration systems. They are continuously variable with .01 dB resolution, have a 100 dB range, an accuracy of ±0.005 dB per-10 dB-increment plus 0.03 dB uncertainty, a typical insertion loss of 18 dB, and a maximum power rating of 1 watt. Input and output impedances are 50 ohms, except for the 70 MHz—units which are 75 ohm-impedances. All Attenuators have a nominal SWR of 1.3, including the SWR of the TNC connectors.

Part Number	Frequency	Mounting	Size	Weight
3230	30 MHz	Unmounted	8-3/4" x 3-1/8" x 2-1/8"	1-3/4 lbs.
3231	30 MHz	Rack	19" x 3-1/4" x 3-15/32"	3-1/4 lbs.
3232	30 MHz	Case	14-1/4" x 4-1/2" x 4-1/2"	4-1/4 lbs.
3260	60 MHz	Unmounted	(22.2 x 7.9 x 5.4 cm)	(0.8 kg)
3261	60 MHz	Rack	(48.3 x 8.3 x 8.8 cm)	(1.5 kg)
3262	60 MHz	Case	(36.2 x 11.4 x 11.4 cm)	(1.5 kg)
3270	70 MHz	Unmounted	8-3/4" x 3-1/8" x 2-1/8"	1-3/4 lbs.
3271	70 MHz	Rack	19" x 3-1/4" x 3-15/32"	3-1/4 lbs.
3272	70 MHz	Case	14-1/4" x 4-1/2" x 4-1/2"	4-1/4 lbs.

System Noise Monitoring

The AILTECH 7300 Series of System Noise Monitors are designed to satisfy those field and production applications that demand simplicity and economy in their instrumentation. The need for noise instrumentation extends beyond the laboratory. Production testing of components, subsystems, etc. and field monitoring of system performance is essential if original equipment goals are to be maintained.

The production testing for Noise Figure of various components (e.g. transistors, amplifiers, etc.) is becoming more necessary in today's drive for large quantities of inexpensive communication components and equipments. The 7300 System Noise Monitor is specifically designed for today's production testing needs, from high speed computer controlled test equipment operations down to the more economical manual test set-ups.

Long term system degradation is usually a prelude to failure but during that period it can mean to the user such things as:

- Higher bit-error rates
- Obscured targets
- Reduced range
- Loss of communication

Monitoring of system performance during actual field operation will alert the operator to anticipate and correct these errors before they occur.

As opposed to laboratory type of instrumentation, the need in production and field applications is for simpler, easier to use, smaller and less expensive products. It is to satisfy these goals that the 7300 series is dedicated.

Applications

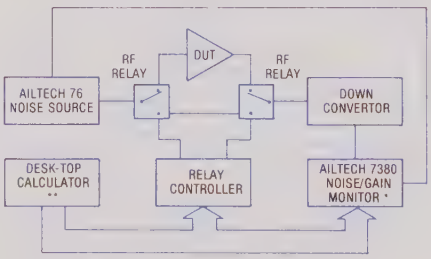
Automated Production Test

Transistors • FETS • Amplifiers • Mixer-amplifiers

The optional bus interface for the 7370 and 7380 provides a low-cost means of adding noise figure and, simultaneously, gain to the growing list of automated measurements. The benefits to be gained include greater throughput, improved measurement consistency, more thorough testing, and less potential for error in the measurement results.

All these factors add up to less testing cost — and with the 7380 Noise/Gain Monitor costs can be even further reduced. This unique instrument determines the gain of the DUT from its noise parameters, thus providing two critical performance criteria with one set-up.

A unique capability when under calculator control is the ability to extract true DUT noise figure from the overall measured noise figure of the set-up using the gain and stored second-stage noise figure. Figure 1 illustrates the typical set-up.

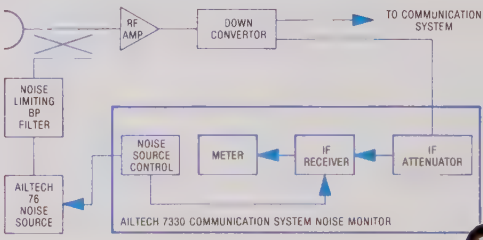


*Option 488 added
**IEEE-STD-488 Bus compatible

Typical automated production test system for simultaneous noise figure and gain measurements of RF and microwave amplifiers

Communications Systems

Conventional noise measurement techniques have also been applied to monitor the performance of satellite communication receiver systems. Using simple adaptation, the operator can measure the noise introduced by the receiving system itself, its antenna, the satellite transponder or radio stars that are used for G/T measurements.



TYPICAL COMMUNICATION SYSTEM INSTALLATION

Radar Installations

The AILTECH 7320 and 7370 System Noise Monitors can, by means of an added option (-02), be adapted for continuous monitoring of a radar WHILE IT IS OPERATING. This feature provides a powerful means of insuring that front end components are performing to full capability. See page 17 for a more detailed discussion.

7380
Noise Figure/ Gain Monitor

*Available with GPIB Interface

The AILTECH 7380 Noise Figure/Gain Monitor is ideal for making rapid, accurate noise figure and gain measurements on semiconductors, amplifiers, receivers, mixers, etc., BCD outputs of noise figure and gain, as well as an optional GPIB interface, if computer control or digital interface is necessary.

Noise figure and gain are measured simultaneously, using solid-state noise sources, and the data are presented on two, 3-digit LED displays.

This instrument is a valuable production tool for automated evaluation of RF and microwave amplifiers (devices, modules or sub-assemblies). See page 12 for a typical application.

Specifications

Input Frequency	10.7, 21.4, 30, 36, 45, 60, or 70 MHz (specify one frequency at time of order)
Bandwidth	10% (nominal)
Sensitivity	–100 dBm (nominal)
Input Signal Level Range	40 dB
Input Impedance	50 ohms
Accuracy (see note)	
Noise Figure	
0 to 6 dB	±0.25 dB
6 to 12 dB	±0.5 dB
Gain	
0 to 40 dB (at constant temperature)	±1.0 dB
Resolution for Noise Figure and Gain	0.1 dB (3 digit display)
ENR Calibration Range	6 to 15.9 dB in 0.1 dB steps
Noise Generator Gate Output (Rear Panel)	BNC, female. "Noise On", +28.00 volts
IF Input (Rear Panel)	BNC, female
Auxiliary Outputs (Rear Panel Cinch 57-30240)	Analog Recorder: 7.5 volts nominal for 0 dB noise figure Signal Level Monitor: uncalibrated Noise Figure/Gain: BCD parallel, TTL, positive logic (requires a control pulse to select Noise Figure or Gain outputs)
Input Power	115/230 VAC ±15%, 50-400 Hz, 15 watts
Operating Temperature	5 to 50°C
Size	5-1/4" H x 17-1/8" W x 13-1/4" D (13.3 x 43.5 x 33.7 cm)
Weight	18 lbs. (8.2 kg) net 22 lbs. (10 kg) shipped

Note: Accuracy in the Automatic mode is specified as related to a manual measurement at a fixed frequency.

Options Available: See pages 17-19

Ordering Information: See pages 14-15

7310
7320
System Noise Monitor

General Specifications For the AILTECH 7300 Series SNM

Indicator	
Input Frequency	10.7, 21.4, 30, 36, 45, 60, or 70 MHz
Bandwidth	10% of center frequency (nominal)
Sensitivity	–70 dBm (minimum)
Signal Level Range	40 dB
Input Impedance	50 ohms (75 ohms can be provided if specified at time of order)
Accuracy (See Note)	
Analog Units	
Full Scale to Half Scale	±0.25 dB for Noise Figure
Half Scale to Quarter Scale	±0.5 dB for Noise Figure
Digital Units	
0 to 6 dB	±0.25 dB
6 to 12 dB	±0.5 dB
Scale Indications	
Noise Figure	0 and 6 dB Full Scale
ENR Calibration Range	6 to 15.9 dB (in 0.1 dB steps)
Noise Generator Gate Output	BNC, female +28.00 Volts for "Noise On," 0.25 Volts for "Noise Off."
Recorder Output (Rear Panel)	1.0 volt across 1K ohms for full scale meter deflection (7310, 7320) 7.5 volts nominal across 1K ohms for 0 dB Indication (7360, 7370)

The AILTECH 7310 System Noise Monitor is a fully automatic instrument that provides a continuous indication of the noise performance of a microwave receiver. Its high accuracy, ease of operation and small size make it ideally suited for permanent installation in receiver systems.

The AILTECH 7310 is an analog, bench-type System Noise Monitor. It provides a fixed IF (see specs for available choices).

The AILTECH 7320 System Noise Monitor is the Full Rack version of the AILTECH 7310. (Photo shown with optional rack mounting brackets).

How to Order Your System Noise Monitor

There are only three steps to take to completely specify your specific model from the 7300 series.

1. Choose the basic model desired from the six units available (7310, 7320, 7330, 7360, 7370 or 7380).
2. Specify your center frequency.
3. Add suffix numbers for your desired options (see pages 17-19).

Example:
P/N 7310 (30)-03-10 specifies an analog, bench mount 30 MHz unit including alarm and front panel manual control options.

7360
7370
System Noise Monitor

IF Input (Rear Panel)	BNC female
Video, Recorder and all Optional Outputs (Rear Panel)	Amphenol 57-20240-1
Input Power	115/230 VAC ±15%, 50-400 Hz, 10 watts
Operating Temperature	5 to 50°C
Size	
7310	5-1/4" H x 7-7/16" W x 13-1/4" D (13.3 x 18.9 x 34.3 cm)
7320	5-1/4" H x 17-1/8" W x 13-1/4" D (13.3 x 43.5 x 33.7 cm)
7360	5-1/4" H x 7-7/16" W x 13-1/4" D (13.3 x 18.9 x 34.3 cm)
7370	5-1/4" H x 17-1/8" W x 13-1/4" D (13.3 x 43.5 x 33.7 cm)
Weight	
7310	10 lbs. Net (4.5 kg) 14 lbs. Ship (6.3 kg)
7320	15 lbs. Net (6.8 kg) 19 lbs. Ship (8.5 kg)
7360	10 lbs. Net (4.5 kg) 14 lbs. Ship (6.3 kg)
7370	15 lbs. Net (6.8 kg) 19 lbs. Ship (8.6 kg)

NOTE:
Accuracy in the Automatic mode is specified as related to a manual measurement at a fixed frequency and includes effects of tracking error and temperature variations. Higher accuracy and resolution is obtainable under most operating conditions.

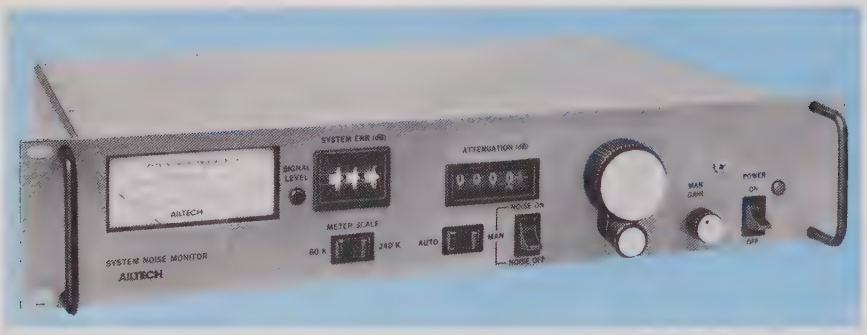
Today the trend in instrumentation for monitoring the condition and performance of operating systems is toward unattended, automated operation under control of, or interfacing with, a computer. This is where the AILTECH 7360 Digital System Noise Monitor comes in — measuring noise figure — Fast, Accurately and Automatically.

The AILTECH 7360 is the digital, bench type, System Noise Monitor. The 7360 has a fixed IF (see specs for available choices).

*The AILTECH 7370 System Noise Monitor is the Full Rack version of the AILTECH 7360. (Photo shown with optional rack mount brackets).

***Available with GPIB Interface**

7330 Communication System Noise Monitor



The AILTECH 7330 Communication System Noise Monitor is designed to provide operating noise temperature monitoring of communication and microwave receivers. It also provides the capability of performing measurements of system sensitivity. The AILTECH 7330 has practical applications to satellite communications systems as well as receivers operating in microwave links.

The AILTECH 7330's high accuracy and ease of operation makes it ideally suited for permanent installation in satellite communication systems. (See page 12 for a typical application.)

Specifications For the AILTECH 7330

Input Frequency	30 or 70 MHz
Bandwidth	10% (nominal)
Sensitivity with attenuator at 0 dB	–52 dBm (minimum)
Input Impedance	75 ohms (nominal); 70 MHz IF 50 ohms (nominal); 30 MHz IF
Automatic Mode	
Input Signal Level Range	40 dB
Accuracy	
Full Scale to Half Scale	±5.0% (in Kelvins)
Half Scale to Three Quarter Scale	±8.0% (in Kelvins)
Full Scale Reading	
Lower Scale	60K (Kelvins) with 5K Resolution
Top Scale	240K (Kelvins) with 20K Resolution
Calibration Range	System ENR of –4.9 dB to +4.9 dB
Manual Mode	
Attenuation Range	100 dB (AILTECH 32 Precision IF attenuator)
Y-Factor measurement error	±0.005 dB/10 dB step +0.03 dB
Rear Panel Input and Output Connectors	
Noise Generator Gate Output	BNC, female, –28.00 VDC for "Noise On," 0.25 Volts for "Noise Off."
Recorder Output	Nominal 1.0 volt for full-scale meter deflection
IF Input	BNC, female
Video, Recorder and all Optional Outputs	Cinch 57-30240 with mating connector
Input Power	115/230 VAC ±15%, 50-400 Hz, 10 watts
Operating Temperature	5 to 50°C
Size	3-1/2" H x 19" W x 12-1/4" D (8.9 x 48.3 x 31.1 cm)
Weight	10 lbs. (4.5 kg) Net 14 lbs. (6.3 kg) Ship

Options Available: See pages 17-19

Ordering Information: See pages 14-15

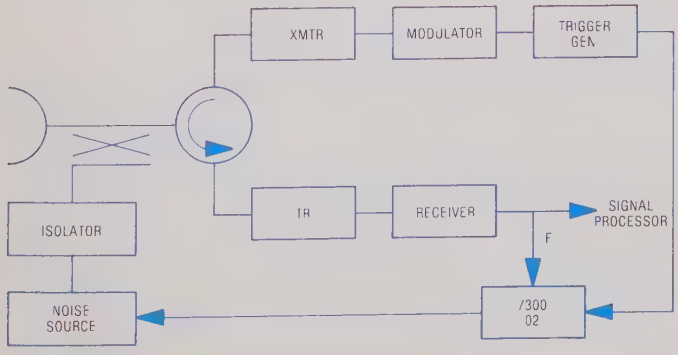
On Line Radar Noise Figure Monitor (Option-02)

Continuous monitoring of the noise figure of a radar while it is operating — a feature of Option-02 — provides an indication of an impending, catastrophic, front end component failure.

The block diagram shows a typical installation. The noise is injected through the directional coupler, typically 20 dB. The isolator is rated to prevent damage to the noise source by the transmit pulse. AILTECH can provide calibrated, high-level noise source/isolator assemblies (sold separately) for most applications. The synchronous radar option offers two modes of operation. In the non-delay mode, the radar provides a trigger at the start of or during the dead-time. If a dead-time trigger is not available, the modulator transmit trigger is used and a fixed delay occurs to set the measurement interval within the dead time.

To Order:

1. Add -02 to the 7320 or 7370 part number.
2. Specify measurement gate width — 20 microseconds minimum.
3. Specify nominal radar PRF.
4. Specify mode — Delay or Non-delay.
5. Specify required delay if applicable.
6. Provide trigger characteristics (amplitude, pulse width, etc.)
7. Specify transmitter peak and average power at the coupled noise injection port.



TYPICAL INSTALLATION

IEEE-STD-488 Interface Option

The AILTECH 7370 and 7380 System Noise Monitors can now be remotely controlled by means of the IEEE-488-1975 Standard Interface Bus. Noise figure and gain measurements, as well as several auxiliary set-up functions, can be programmed and monitored using a calculator or computer with IEEE-488 I/O Bus compatibility.

This option provides a low-cost means of adding noise figure (and, simultaneously, gain*) to the growing list of automated measurements. In the past, noise figure has usually required a separate setup, necessitating removal of the device-under-test (DUT) from a test station; thus adding time, cost, inconvenience, and a greater potential for error to the performance verification of the DUT — either in the design/development or production phase.

With the exception of the added functions noted, the option-equipped instruments are identical in features and performance to the standard units; for example, BCD parallel and analog outputs proportional to noise figure and signal level are available on the rear panel.

*7380 only

To order, add -488 to the 7370 or 7380 part number.

Control Functions and Outputs

Control

Standby — The noise source can be enabled or disabled under bus control, thus becoming a passive termination while other tests are made.

Range — Available only on 7370's equipped with option 100 (order option 488B). Instruments so equipped have an added extended measurement range of −10 to 29.9 dB. The range — either normal (0 to 19.9 dB) or extended — can be selected via the bus.

Auxiliary — A user-defined, bus-controlled output on the interface board. This output can be used for such functions as input selection, external level control, etc.

Outputs

Noise Figure

Gain (7380 only)

Signal Level — A fault indication. If the SNM Signal Level Light is extinguished for any reason, usually an indication of a fault in the IF amplifier chain; a noise figure of 00.0 dB will be placed on the bus data lines. This unique value can serve as a fault indicator to the controller.

Added Performance With Optional Features

Introduction

In addition to the Standard Bus Interface and Synchronous Monitor options, AILTECH offers a line of low-cost options to enhance performance and simplify operation for specific applications. These options are described below while the chart on the opposite page is provided as an aid to illustrating applicability of specific options to the various models.

OPTION NO.	TITLE	DESCRIPTION
03	**Noise Figure Alarm**	A relay operates when the noise figure exceeds a variable, internally preset value. Relay contacts (SPDT) are brought out to the rear panel connector. The alarm DISABLE switch is mounted on the front panel.
04	**Frequency Converter**	A fixed frequency, internally mounted downconverter used to translate a specific input frequency to the basic SNM IF. Connection to the IF is via rear panel patch cable. The LO can be preset at the factory for any value between 180 and 265 MHz. Conversion loss is 6 dB nominal.
06	**Special Paint**	Upper front panel only painted per customer requirements (customer to supply paint).
07	**High Sensitivity**	A low-noise preamplifier is internally mounted to provide a nominal 20 dB improvement in sensitivity. IF input is via the preamplifier. Input noise figure is 3 dB, nominal. Typical sensitivity with this option for the 7320, 7370 is –100 dBm (–72 dBm for the 7330).
09	**RF Mixer**	A broadband mixer is mounted on the rear panel. The mixer will accept RF and LO inputs from 10 to 1000 MHz. Connection to the SNM IF input is via rear panel patch cable. Nominal conversion loss is 6 dB.
10	**Manual Front Panel Controls**	The AUTO-MANUAL mode switch, noise generator ON-OFF switch, and MANUAL GAIN control, used for manual Y-factor measurements are brought out to the front panel.
11	**Rack Mount Adaptors**	A pair of angle adaptors which bolt on to the 7320, 7370 and 7380 side frames to make these instruments suitable for standard 19 inch relay rack mounting. (NOTE: the 7330 front panel is 19 inches wide and can be rack-mounted without these adaptors).
12	**10 Volt Recorder Output**	A second analog recorder output which provides 10 volts for full-scale deflection is added. The nominal 1.0 volt recorder output is retained, but the External Meter output is deleted.
13	**Front Panel Connectors**	The IF Input and Noise Source Output connectors are brought out to the front panel.
15	**Slide Mounting**	This option provides a pair of non-tilt slides mounted to the 7320, 7370, or 7380 side frames. Slide type is Zero, C300S-14. Requires -11 option.
100	**Range Extension, 29.9 dB**	Extends the noise figure measurement range of the digital units to 29.9 dB by means of a front panel RANGE switch. Can be bus-controlled if the 488 Option is installed. Accuracy in the extended range is ±0.5 dB for 10 to 15 dB indication, ±1.0 dB for 15 to 29.9 dB.
101	**Range Extension Output**	Provides a switch closure at the rear panel connector when the Extended Range is selected (–100 Option must be installed).

Option-Model Compatibility

Introduction

The Matrix below illustrates compatibility of the various options with specific 7300 models. In some instances, where a particular option is not available as standard on a specific model, it may be installed as a special at added cost. These situations are designated "SP" in the chart. Please consult the factory for additional information and pricing. Applicable standard options are marked with a dot. A blank position means that option is not applicable to a specific model.

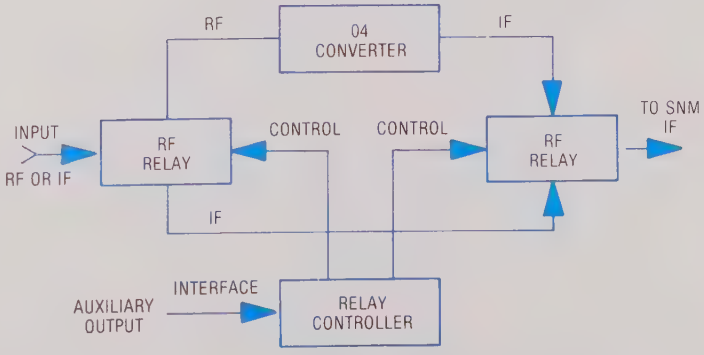
SNM MODEL	OPTION NUMBER													
	02	03	04	06	07	09	10	11	12	13	15	100	101	488
7310	SP	•	SP	•	SP	SP	•		•	SP				
7320	•	•	•	•	•	•	•	•	•	•	•			
7330		SP		•	•				•	SP				
7360		•		•		SP	•		•	SP		•	•	
7370	•	•	•	•	•	•	•	•	•	•	•	•	•	•
7380		•	•	•		•	•	•	•	•	•	•	•	•

Special Applications

Occasionally, even the wide range of options available with the various System Noise Monitors do not solve a particular application problem. In these instances, AILTECH will be pleased to bid on a special configuration designed to solve your measurement difficulty.

Generally, these special units offer such features as dual-frequency operation, control of more than one noise generator, special meter scales and ENR ranges, etc. A typical "special" is illustrated in the accompanying diagram. This unit offers dual-frequency operation with input frequency selection under control of the Standard Interface Bus.

The basic unit is a 7370 (or 7380) equipped with the optional (04) converter and bus interface (488). The auxiliary control codes (not normally used in standard units) is utilized to control the RF relays for frequency selection. All components are mounted within the SNM enclosure.



TYPICAL SPECIAL APPLICATION

Noise Generation

Featuring

- **Accuracy**
- **Broad Frequency Coverage**
- **Complete Capability**
- **NBS Traceability**
- **Calibration Service**

The AILTECH line of noise generators offers full coverage to 40 GHz with solid-state and gas-discharge noise generators as well as a DC to 9 GHz thermal noise standard.

Solid-State Noise Generators

The AILTECH 7600 Series Solid-State Noise Generators cover 10 MHz to 18 GHz in four units **with one device (P/N 7618) spanning the entire range from 1 to 18 GHz.**

The major contributor to measurement uncertainty in most noise figure set-ups is the noise generator. Mismatch and calibration accuracy are the primary causes. The noise generating mechanism of all the units described here is decoupled from the output port by 12 to 20 dB (depending upon model) resulting in very low VSWR, thus, minimizing mismatch uncertainty.

In addition, every unit in this series is calibrated in production by means of the AILTECH 82 Noise Calibration System*. The uncertainties quoted — as low as ±0.25 dB at frequencies in the 8.2 to 18 GHz range — **are worst-case (not root-sum-of-squares)** — thus, 100% of the units produced will fall within the accuracy limits specified at every calibration frequency.

High-Level Noise Sources

The AILTECH line also features high-level (ENR up to 35 dB) noise sources for systems applications. These units are described on the rear cover of this brochure.

Specifications.... 7600 Series Solid-State Noise Generators

PART NUMBER	7615	7616	7617	7618
Frequency Range (GHz)	0.01-1.5	1-12.4	12.4-18	1-18
Excess Noise Ratio (nominal, dB)	15.5	15.5	15.5	15.0
Flatness vs. Frequency (dB)	±0.5	±0.5	±1	±1
VSWR (maximum)	1.2	1.2	1.3	1.2, 1 to 12.4 GHz 1.3, 12.4 to 18 GHz
Input Connector	BNC Female	BNC Female	BNC Female	BNC Female
Output Connector	N Male	N Male	SMA Female	SMA Female
Input Power	+28 volts @ 20 ma. max.	+28 volts @ 20 ma. max.	+28 volts @ 20 ma. max.	+28 volts @ 20 ma. max.

Calibration Frequencies and Uncertainties

	CALIBRATION FREQUENCIES (GHz)										
Part Number	0.03	0.3	1.0	1.5	2	3.95	8.2	9.8	12.4	15.0	18.0
7615	X	X	X	X							
7616			X		X	X	X	X	X		
7617									X	X	X
7618			X		X	X	X	X	X	X	X
Uncertainty (± dB)	0.3	0.3	0.3	0.3	0.3	0.28	0.25	0.25	0.25	0.25	0.25

Calibration Service

EID provides excess-noise-ratio (ENR) calibrations to an absolute accuracy of ±0.11 dB at specific frequencies. Results are directly traceable to NBS where primary standards have been established.

Your noise sources will be calibrated using the highly regarded AILTECH 82 Noise Temperature Calibration System. It can accommodate noise sources in several waveguide sizes as well as coaxial types from 10 MHz to 18 GHz. Consult the factory for more information on this unique, valuable service.

*This system was reviewed by the National Bureau of Standards in 1968 (NBS Report #9729 "Error Analysis of the AIL Noise Measuring System," W.C. Daywitt, Sept. 1968). Copies of this report are available from Eaton Corporation, Electronic Instrumentation Division upon request.

7009 Hot/Cold Standard Noise Generator

When used with the 13611 Precision Test Receiver (see pages 8 and 9), the AILTECH 7009 provides a noise-figure measurement system capable of better than ±0.1 dB accuracy. The noise-source standard employs two resistive terminations: one is immersed in liquid nitrogen (77.3K), the other is in a proportionally-controlled oven set to the temperature of boiling water (373.2K). For the utmost in accuracy and repeatability, front-panel connections are via 14 mm precision connectors. The terminating impedances are carefully controlled so that they track each other, in both magnitude and phase, over the full frequency range of the instrument. Thus, mismatch uncertainties are virtually eliminated.

Specifications

Frequency Range	0 to 9 GHz
VSWR	1.15 maximum
Impedance Tracking	The distance between the complex impedance points of the hot and cold terminations (plotted on a Smith chart) is less than the diameter of a circle corresponding to an SWR of 1.05 from DC to 7 GHz, and 1.10 from 7.1 to 9 GHz.
Termination Temperature	Hot 373.2 ±1 Kelvins Cold 77.3 ±1, –0 Kelvins
Noise Temperature	Termination temperature ± frequency correction
Output Connectors	14 mm precision (GR-900BT)
Line Power	115/230V ±10%, 50 to 400 Hz, 20 watts (nominal)
Size	9-1/4" W x 15" H x 14-3/4" D (23.5 x 38.1 x 32.5 cm)
Weight	16 lbs. (7.3 kg) net 27 lbs. (12.3 kg) shipped

Gas-Discharge Noise Generators

AILTECH Gas-Discharge Noise Generators are two port devices employing argon-filled tubes. Two coaxial units cover 0.2 to 5 GHz, and four waveguide units cover 8.2 to 40 GHz. All units in the 70 Series are powered by the AILTECH 7175 Triggerable Power Supply (see adjoining box). One port of these units must be terminated.

Specifications

TABLE I

Part Number	7010	7012	7052*	7091*	7053*	7096
Freq. Range (GHz)	0.2-2.6	2-5	8.2-12.4	12.4-18	18-26.5	26.5-40
ENR (dB), ±0.25 dB**	15.65	15.75	15.7	16.1	16.1	16.3
VSWR ON (nom.)	1.15	1.5	1.3	1.3	1.35	1.3
VSWR OFF (nom.)	1.5	2	1.2	1.2	1.35	1.2
Output Connector	Type N Female	Type N Female	UG-39/U	UG-419/U	UG-595/U	UG-599/U

*Termination provided

**Gas-discharge tube only

7175 Triggerable Gas Noise Generator Power Supply

This instrument provides the user with the means to perform both manual and automatic noise figure or noise temperature measurements using an AILTECH Gas-Discharge Noise Generator. It is capable of igniting and controlling all generators in the AILTECH 70 Series.

The 7175 Power Supply and a 70 Series Noise Generator can operate "stand-alone" for noise performance measurements by means of the manual Y-factor technique; however, the unit also offers a unique Remote mode of operation which permits triggering from a 28 volt pulsed source normally used to drive solid-state noise sources.

The Remote feature provides the means for automatic noise figure measurements using microwave gas-discharge noise generators up to 40 GHz with direct-reading noise figure instrumentation such as the AILTECH 7514 Precision Automatic Noise Figure Indicator and the 7300 Series System Noise Monitors.

Power Input	115/200 VAC ±10%, 50/60 Hz, 120 watts
Size	17" W x 14-7/8" L x 5-1/4" H (43.2 x 37.8 x 13.3 cm)
Weight	20 lbs. (9.1 kg) net 25 lbs. (11.4 kg) ship

Noise Source Calibration System

Control and Calibration Assembly

Waveguide Noise Standards

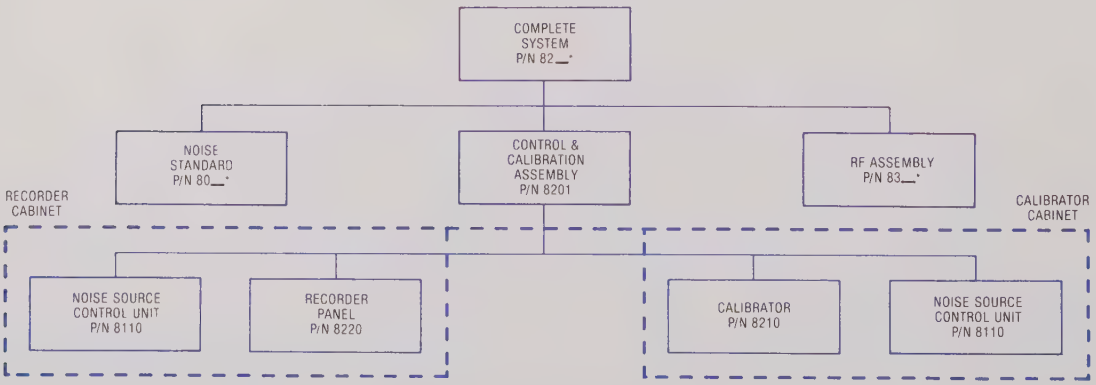
The AILTECH 82 System is the only commercially available instrumentation designed specifically for the calibration of Noise Sources. With this system you can now provide your Standards Laboratory with the capability for calibrating Noise Sources, "in-house," at considerable savings.

As shown in the illustration below, a complete system operating in a specific frequency band is comprised of three major assemblies: a Noise Standard, an RF Assembly, and a Control and Calibration Assembly. To expand your existing system you need only acquire the appropriate Noise Standard and RF Assembly. Additional Preamplifiers (AILTECH 8230), normally part of the AILTECH 8210, may also be purchased to expedite changing frequency ranges.

The Control and Calibration Assembly includes a radiometric receiver, a recorder and two 8110 Control Units for supplying current-regulated power to gas-discharge Noise sources (AILTECH 70 and 80 Series). These units may also be modified to provide power for solid-state noise generators and standards at additional cost.

The AILTECH 80 Noise Standards include both solid-state and gas-discharge types. Above 8.2 GHz, the Noise Standards are waveguide units using precision-ground, argon-gas tubes.

The AILTECH 83 RF Assemblies are coaxial up to 8 GHz, and waveguide above that frequency. Each Assembly above 1 GHz consists of a termination, tuner, isolator, mixer, and a mounting stand. Below 2 GHz, a low-noise preamplifier is also provided.


COMPLETE SYSTEM P/N 82__*
NOISE STANDARD P/N 80__*
CONTROL & CALIBRATION ASSEMBLY P/N 8201
RF ASSEMBLY P/N 83__*
RECORDER CABINET
CALIBRATOR CABINET
NOISE SOURCE CONTROL UNIT P/N 8110
RECORDER PANEL P/N 8220
CALIBRATOR P/N 8210
NOISE SOURCE CONTROL UNIT P/N 8110

*LAST TWO DIGITS INDICATE FREQUENCY RANGE.

Complete System Specifications

System P/N	Frequency Range (GHz)	Standard P/N	RF Assembly P/N	Estimated* Uncertainty
8211A	0.01-1	8011	8310	**
8211	1-2	8011	8311	**
8212	2-4	8012	8312	±0.22 dB
8213	4-8	8013	8313	**
8252	8.2-12.4	8052	8352	±0.11 dB
8291	12.4-18	8091	8391	±0.11 dB
8353	18-26	8053	8353	**

*Based on arithmetic sum of 8201 comparison accuracy with specified RF Assembly, and uncertainty of the Noise Standard (NBS) calibration where applicable. See NBS Special Publication 250, Section 7 for availability of NBS calibration services and fee schedule.

**Consult factory for estimated uncertainties in these bands.

RF Assembly Specifications

P/N	Frequency Range (GHz)	VSWR, Max (Using Tuner)	Input Connector	Comparison* Uncertainty	Mounting Base Length — in. (cm)	Weight — lbs. (kg)
8310	0.01-1	1.30	14mm Precision	±0.20 dB	36 (92)	24 (10.9)
8311	1-2	1.10	14mm Precision	±0.09 dB	36 (92)	30 (13.6)
8312	2-4	1.05	14mm Precision	±0.06 dB	36 (92)	38 (17.3)
8313	4-8	1.05	14mm Precision	±0.07 dB	36 (92)	38 (17.3)
8352	8.2-12.4	1.05	Cover Flange WR-90	±0.05 dB	36 (92)	40 (18.2)
8391	12.4-18	1.05	Cover Flange WR-62	±0.05 dB	36 (92)	38 (17.3)
8353	18 -26	1.15	Cover Flange WR-42	±0.1 dB	36 (92)	37 (16.8)

*Uncertainty of the differential ENR measured on the 8201 when used with the specified front end, appropriate standard, and a noise generator for calibration with VSWR of <1.2.

Noise Standard Specifications

P/N	8011	8012	8013	8052	8091	8053
Frequency Range (GHz)	0.01-2	2-4	4-8	8.2-12.4	12.4-18	18-26
Type	Solid-State	Gas-Discharge	Solid-State	Gas-Discharge	Gas-Discharge	Gas-Discharge
VSWR (max)	1.15	1.15	1.2	1.15	1.15	1.25
ENR (dB)	15.5 ±0.5	15.0 ±0.5	15.5 ±0.5	15.5 ±0.5	15.5 ±0.5	15.9 ±0.5
ENR* Uncertainty (dB)	—	±0.16	—	±0.06	±0.06	—
Output Connector	Precision Type N Male	Precision 14 mm	Precision Type N Male	Cover Flange WR-90	Cover Flange WR-62	Cover Flange WR-42
Power Required	28.00 VDC 10 mA	AILTECH 8110	28.00 VDC 10 mA	AILTECH 8110	AILTECH 8110	AILTECH 8110
Size-in. (cm)						
length	4-1/2 (11.4)	14-1/2 (37)	4-1/2 (11.4)	12 (30.5)	12 (30.5)	11 (27.9)
height	1 (2.5)	5 (12.7)	1 (2.5)	6 (15.3)	6 (15.3)	6 (15.3)
width	1 (2.5)	4 (10.2)	1 (2.5)	4 (10.2)	4 (10.2)	4 (10.2)
Weight— lbs. (kg)	7/16 (0.2)	15 (6.8)	7/16 (0.2)	6 (2.7)	6 (2.7)	6 (2.7)

*The physical and electrical characteristics of the Noise Standard are such that its Excess Noise Ratio (ENR) can be calibrated by the National Bureau of Standards to the stated maximum uncertainty — units are provided with AILTECH factory calibration which, typically, will add ±0.05 to the stated uncertainties.

High Level Noise Sources

Excess Noise Ratios (ENR) to 35 dB Up to 15% Bandwidth (10 MHz to 18 GHz)

AILTECH 7650, 7660

(The difference between these two units is in the type of output connector — 7650 has a type N-Male while 7660 has a 3 mm-female.)

The convenience of solid-state, low-power requirements, small size and weight, plus the high-level output makes the AILTECH noise sources ideal for system noise monitoring applications. A high excess noise ratio permits the user to inject noise into a receiver system through a coupler and still attain a reasonably high, injected noise power in the system for measurement of noise figure or operating noise temperature. Use of high-value couplers reduces noise degradation of the receiver when the monitoring function is not active. Small size and the need for only a single coaxial power connection make antenna feed mounting particularly convenient.

Operating up to 18 GHz with typically a 15-percent bandwidth, these devices can be provided with excess noise ratios of as high as 35 dB.

EID's experience in the manufacture, characterization, and calibration of noise measurement equipment permits specification of the ENR of a typical device to within ±0.5 dB. Isolators or couplers can be supplied at additional cost (or supplied by the customer), and the calibration can be performed at the output port thus eliminating another source of system error.

All units operate from +28 volts DC at less than 20 mA. This greatly simplifies operating the units at remote locations.

TABLE E
Specifications

Part Number	7650-X[1]	7660-X[1]
Frequency Range	10 MHz to 18 GHz	10 MHz to 18 GHz
Bandwidth	Up to 15 percent	Upt to 15 percent
Maximum Excess Noise Ratio[2]	See graph	See graph
Typical VSWR[3]	4:1	4:1
Output Connector	Type N-male	3 mm-female
Input Connector	BNC-female	BNC-female
Power Required	28.0 V at 20 mA maximum	28.0 V at 20 mA maximum
Overall Dimensions (nominal)	1" x 1" x 4" (2.54 x 2.54 x 10.2 cm)	1/2" x 1/2" x 2-1/2" (1.27 x 1.27 x 6.4 cm)
Weight	3.5 oz. (99 g)	2.7 oz. (76.5 g)

For additional information on AILTECH Instruments please call or write
Eaton Corporation,
Electronic Instrumentation Division,
5340 Alla Road
Los Angeles, CA 90066
Telephone (213) 822-3061

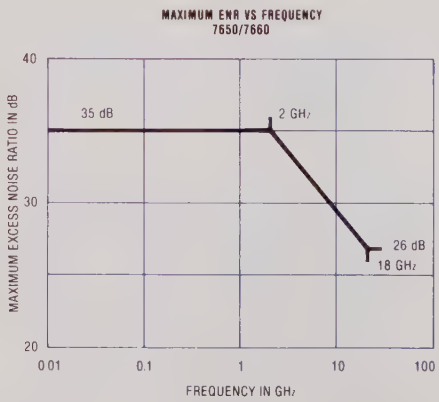
EATON
Advanced Electronics

RF Isolated Units

Radar noise monitor applications (see page 17) generally require protection of the noise source from the transmitter power appearing at the noise injection port. AILTECH P/N's 230450 and 230450A are noise generator-isolator assemblies, operating in air traffic control bands, designed specifically for this purpose. Other frequency bands can be provided on request.

TABLE I

Part Number	230450	230450A
Frequency (GHz)	2.7 to 2.9	1.2 to 1.4
Isolation (dB)	40	40
Max. Peak Incident Power (kW)	10	10
Nominal ENR (dB)	34	34



NOTES

1. Suffix digits assigned on receipt of order.
2. Higher ENR and wider bandwidths available at additional cost.
3. RF isolations available at additional cost.

Measuring Microwave Noise

Measuring Noise Performance Factors

INTRODUCTION

EATON Corporation, Electronic Instrumentation Division (EID), by virtue of its long, continuous association with receiver/amplifier noise measurement technology, is uniquely qualified to discuss the theory and measurement techniques of this somewhat subtly difficult subject.

Many will remember the company—originally known as the Microwave Instruments Division of Airborne Instruments Laboratory (AIL)—as a producer of high-quality noise instrumentation starting with the Type 72 Automatic Noise Figure Indicator almost thirty years ago.

Since that time, EID has developed a continuous succession of progressively more accurate and precise noise instrumentation—including:

The 7514 Precision Automatic Noise Figure Indicator—the industry workhorse.

The 7300 Series of System Noise Monitors for low cost systems applications.

Thermal Noise Standards (7009) and Precision Test Receivers (136) for ultra-accurate applications.

The first commercially available Noise Calibration System (Type 82).

AND—MOST RECENTLY—

The 2075 Noise-Gain Analyzer.

NOISE

Any stochastic function of time of specified length whose Fourier Series components each have a two dimensional normal distribution and random phase can be considered noise provided that the quadratic content of no single component is an appreciable percentage of the total.

NOISE—GENERAL

WHAT IS IT?

Any random or aperiodic signal which tends to obscure a desired signal and interferes with the extraction of intelligence from that signal.

Some types of periodic interference are also aften considered noise. These include:

- Vehicle Ignition Radiation
- Electric Motor Brush Noise
- Vibration
- Hum
- X-ray and Diathermy Machine Interference

These are characterized in another technology (EMI) and not considered here.

ORIGINS OF NOISE

Aperiodic—random noise can originate from a number of sources. Within the receiver itself, however, noise is generated by both the passive and active components. Noise generated within passive, dissipative components—typically resistors—is called thermal noise because its magnitude can be directly related to the physical environment.

There are several sources of noise within active components.

The most important in the RF/Microwave region are:

Thermal noise—due to the bulk resistance of the semiconductor material.

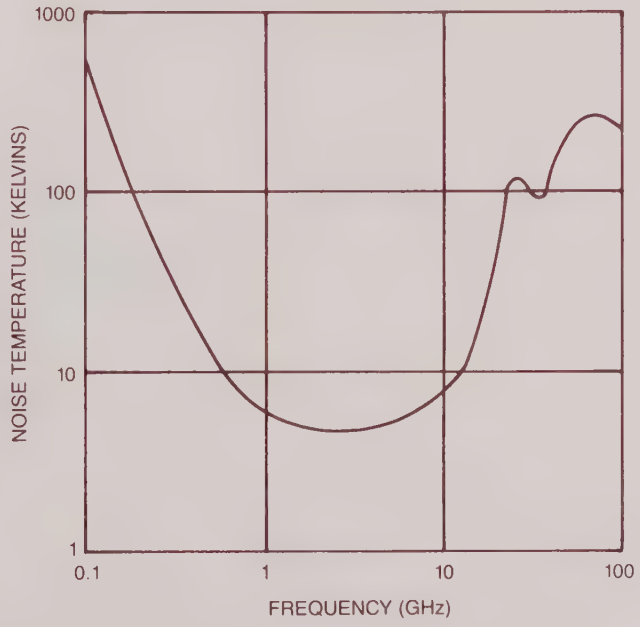
Shot noise —which results from random movement of charge carriers under impetus of bias.

Low frequency effects include partition noise and l/f noise.

Most of the parameters discussed here are measures of the RF/Microwave internal noisiness of receiver systems, subassemblies, components, and devices.

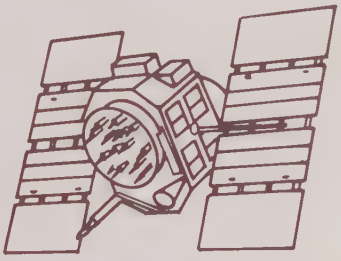
THE IMPORTANCE OF RECEIVER NOISE

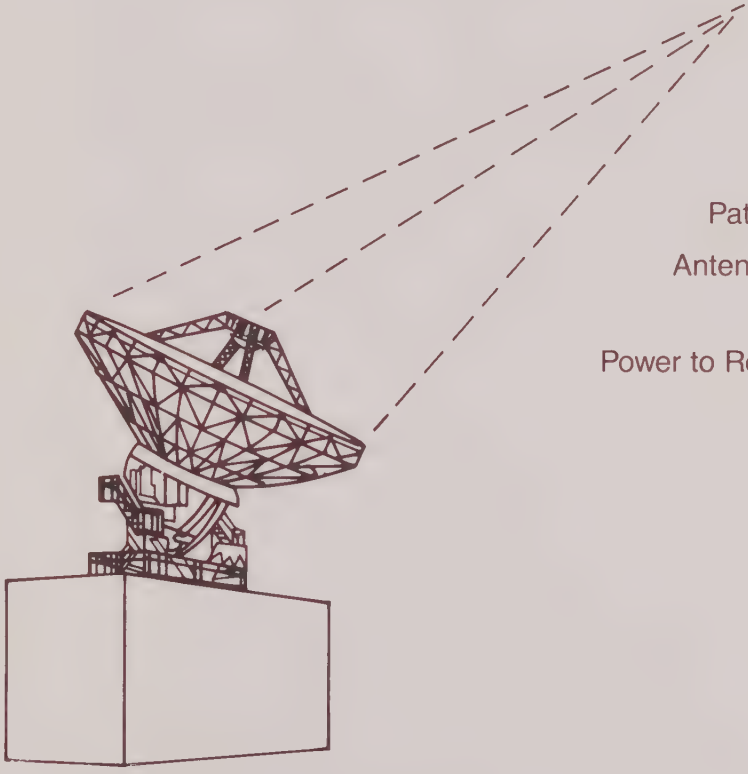
In the most heavily utilized segment of the electromagnetic spectrum it is the inherent limiting factor on the sensitivity of a receiving system.



Plot of Ideal Antenna Noise Temperature vs. Frequency

NOISE IS A COST FACTOR





ERP + 40 dBm (10 watts)

Path Loss −200 dB

Antenna Gain +60 dB

Power to Receiver −100 dBm

Receiver Noise Temp 210 K

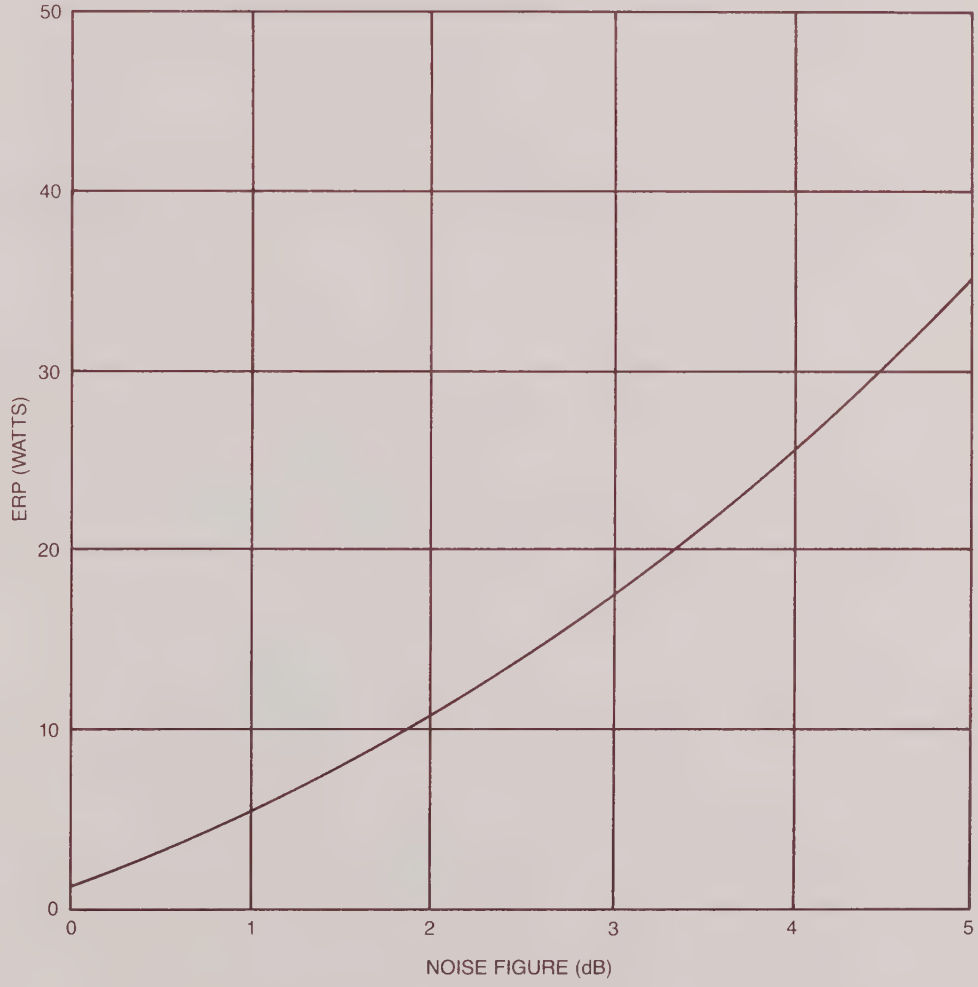
Noise in 1 MHz BW −115 dBm

Noise in 100 MHz BW +20 dB

Receiver Noise Power −95 dBm

System Noise Margin ~~+5 dB~~ −5 dB

NOISE = WATTS = $



Effective Radiated Power vs. Noise Figure for S/N = 1

WHY NOISE FIGURE?

Noise figure is a fictitious figure of merit describing the internal noisiness of a transducer. It does not truly exist in the same sense as a voltage or current.

So the question is valid.

Noise figure is unique—

It permits specification of noise performance independent of other transducer parameters (gain, bandwidth, etc.)

It is a common language that permits all levels of system manufacture to specify noise performance.

- System
- Receiver Subsystem
- LNA Subassembly
- Amplifier Module
- Device

The overall system performance can be characterized in terms of its lower level components.

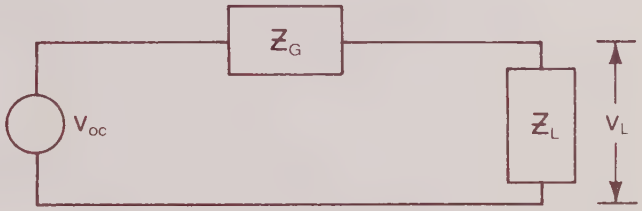
BASIC CONSIDERATIONS

- AVAILABLE POWER
- THERMAL NOISE
- NOISE CONTRIBUTION OF A LOSSY ELEMENT
- THE GENERAL NOISY TRANSDUCER
- NOISE PARAMETER DEFINITIONS
- COMPLICATIONS
- THE GENERAL MEASUREMENT TECHNIQUE
- SUMMARY

AVAILABLE POWER

The power that a source network could deliver to a conjugately matched load.

v_{oc} = open circuit source voltage
$\mathbf{Z}_G$ = source impedance
$\mathbf{Z}_L$ = load impedance
v_L = voltage across the load



$$v_L = \frac{v_{oc}}{2}$$

If $\mathbf{Z}_L = \mathbf{Z}_G^*$, $\mathbf{Z}_G = R_G + jX_G$
$\mathbf{Z}_L = R_G - jX_G$

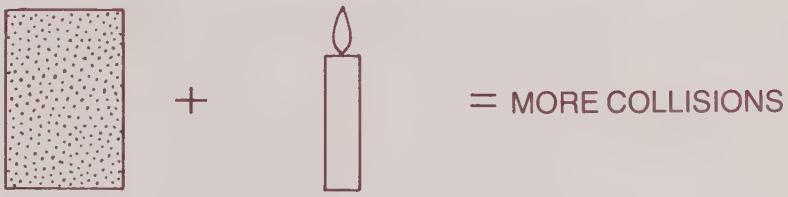
$$P_A = \frac{v_L^2}{R_e(\mathbf{Z}_L)} = \frac{v_{oc}^2}{4R_G}$$

THERMAL NOISE

Developed mathematically and verified empirically by Johnson and Nyquist in 1928.

Results from random, thermally agitated movement of charge carriers within a dissipative element (resistor).

Similar in concept to gas molecules in a closed container. Random movement results in collisions between molecules. Add heat—the movement is faster and more violent. Hence more collisions.

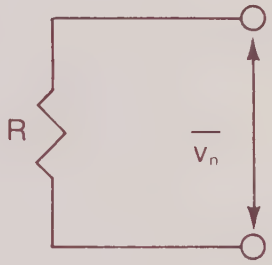


If each collision represents an impulse of energy

THERMAL NOISE

$\overline{v_n}$ = RMS open circuit noise voltage at the resistor terminals.

$$\overline{v_n} = 2\left[kT \int R(f)\, h(f)\, df\right]^{1/2}$$



R(f) = Resistance as a function of frequency.
≈ A constant for most practical frequency ranges.

T = in kelvin

h(f) = Planck's Factor
≈ 1 for practical frequencies and temperatures
~~1%~~ 10% deviation from unity at 290K at a frequency of 1300 *GHz.*

k = Boltzman's Constant = 1.38×10^{-23} joules/kelvin

This leaves, $\int df$ which is simply bandwidth (B)

$\overline{v_n}^2 = 4kTRB$

AND, Available Noise Power (N),

$$N = \frac{v_n^2}{4R} = \frac{4kTRB}{4R}$$

$$\boxed{N = kTB}$$

watts

Recognize that this is an approximation.

THERMAL NOISE NUMERICAL EXAMPLE

GIVEN:

$T = 290K, 62°F, 17°C$

$B = 1\ Hz$

$N = (1.38 \times 10^{-23})(290)(1)$

$N = 4 \times 10^{-18}\ mw$

$-174\ dBM$

FOR BANDWIDTH—ADD $10\ LOG_{10}\ B\ (Hz)$

e.g.: 10^6 (1 MHz) = 60 dB

N = −114 dBM (1MHz)

OR COMPUTE IN MHz

10 MHz = + 10 dB

N = −104 dBM (10 MHz)

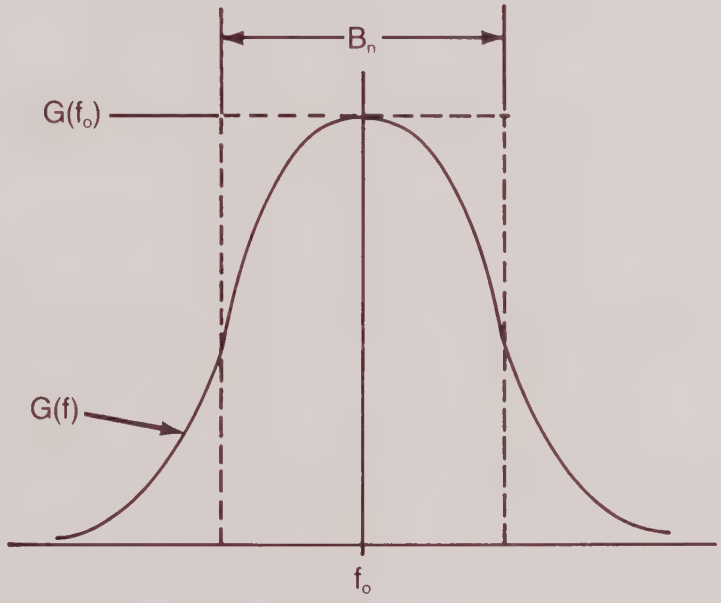
DIFFICULTIES OF NOISE MEASUREMENT:

MEASUREMENT OF RF AND MICROWAVE POWER.

SIGNALS ARE APERIODIC—RANDOM IN AMPLITUDE—ELECTRONIC GARBAGE!

LEVELS ARE EXTREMELY SMALL.

NOISE BANDWIDTH

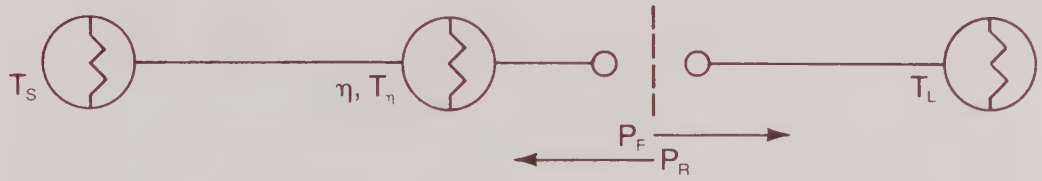


Area under the rectangle equals the area under the actual power gain versus frequency curve

$$B_n = \int_0^\infty \frac{G(f)df}{G(f_o)}$$

NOISE TRANSMITTANCE OF A LOSSY ELEMENT

GIVEN: A matched system in thermal equilibrium.



If $T_S = T_\eta = T_L$, then from the 2nd law of thermodynamics

$$P_F = P_R$$

$P_F = \eta P_s + P_\eta$, $P_R = P_L$
$P_\eta = P_L - \eta P_s$: Lossy element contribution to the forward noise power.
$P_\eta = kT_L - \eta kT_S$ but, $T_\eta = T_L = T_S$
$P_\eta = (1-\eta)kT_\eta$

η is defined as transmission efficiency – a dimensionless ratio equal to $\frac{P_{OUT}}{P_{IN}}$

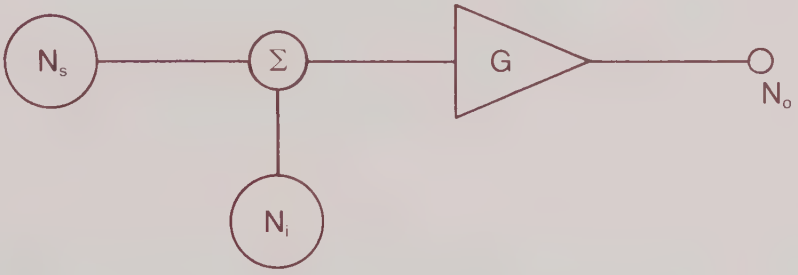
In general, then:

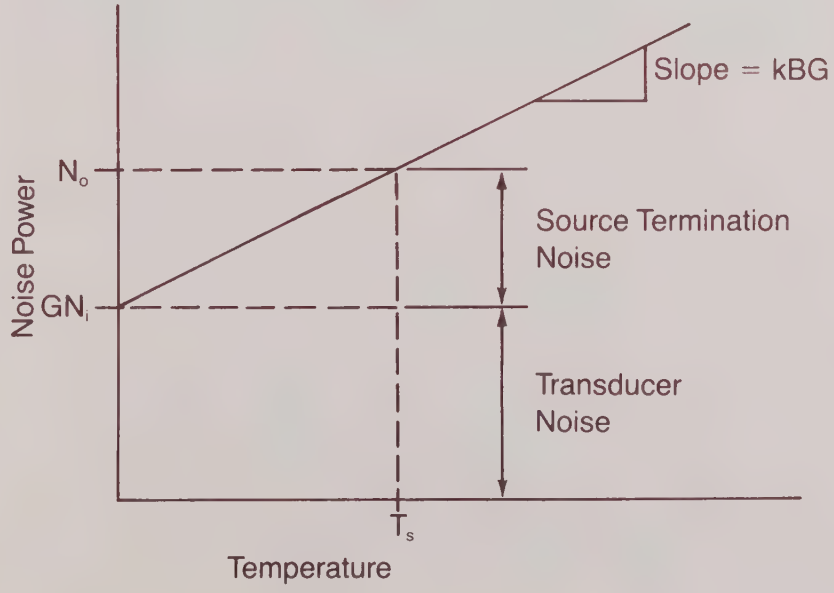
$T_F = \eta T_S + (1-\eta)T_\eta$

DOES IT WORK? TEST BY BOUNDARY CONDITIONS
Infinite loss: $\eta = 0$
$T_F = T_\eta$
No loss: $\eta = 1$
$T_F = T_S$
Just what we would expect.

THE GENERAL NOISY TRANSDUCER

N_s = noise power generated by the source termination.
$= k T_s B$
N_i = noise power generated internally to the transducer referred to the input.
Noise figure is a figure of merit describing this noise.
N_o = noise power available at the transducer output.
$N_o = GN_s + GN_i = G(N_s + N_i) = GkT_sB + GN_i$
A simple linear form of $N_o = f(T_s)$ with:
y intercept $= G N_i$
slope $= GkB$





NOISE FIGURE (IEEE DEFINITION)

At a specified input frequency the ratio of 1) the total noise power per unit bandwidth at a corresponding output frequency available at the output Port *when the Noise Temperature of its input termination is standard (290°K) at all frequencies (Reference: Definition for Average Noise Factor)* to 2) that portion of 1) engendered at the input frequency by the input termination at the Standard Noise Temperature (290°K).

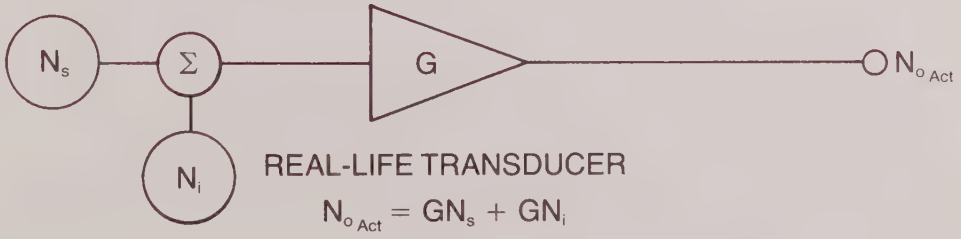
Note 1: For heterodyne systems there will be, in principle, more than one input frequency corresponding to a single output frequency, and vice versa; for each pair of corresponding frequencies a Noise Factor is defined. *2) includes only that noise from the input termination which appears in the output via the principal-frequency transformation of the system, i.e., via the signal-frequency transformation(s), and does not include spurious contributions such as those from an unused image-frequency or an unused idler-frequency transformation.*

PRACTICAL DEFINITION

A comparison between the noise output of the actual transducer to that of an ideal noiseless transducer of otherwise identical characteristics—when the input (source) termination is at the standard reference temperature, 290 K (T_o).

IDEAL TRANSDUCER

$N_{o\ Ideal} = GN_s$



REAL-LIFE TRANSDUCER

$N_{o\ Act} = GN_s + GN_i$

NOISE FIGURE
GRAPHICAL REPRESENTATION

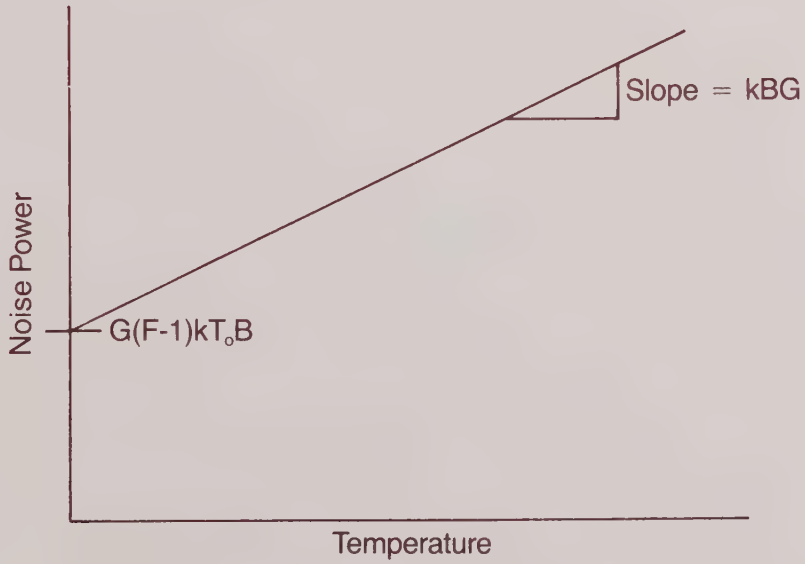
$$F = \frac{N_{o\ Act}}{N_{o\ Ideal}}$$

$$F = \frac{GN_s + GN_i}{GN_s} \quad \Big| \quad T_s = T_o$$

$$F = \frac{N_i}{N_s} + 1 \quad \Big| \quad T_s = T_o$$

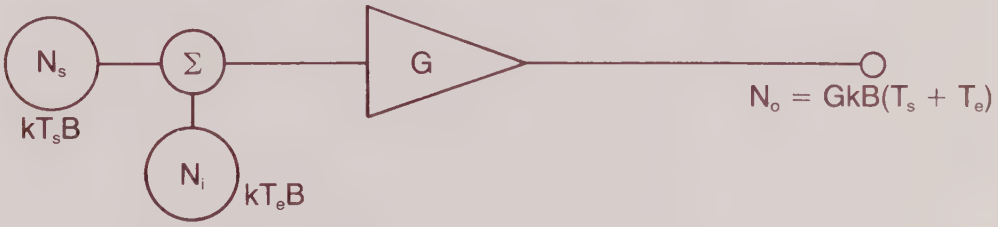
$$N_i = (F-1)\,kT_oB$$

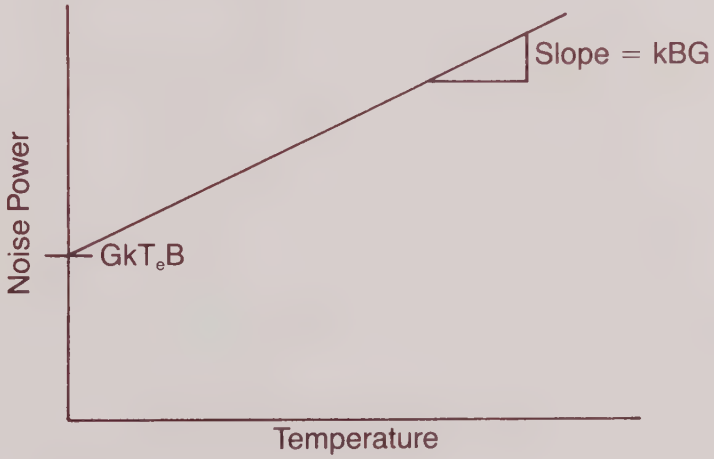
$$N_o = GkT_sB + G(F-1)kT_oB$$



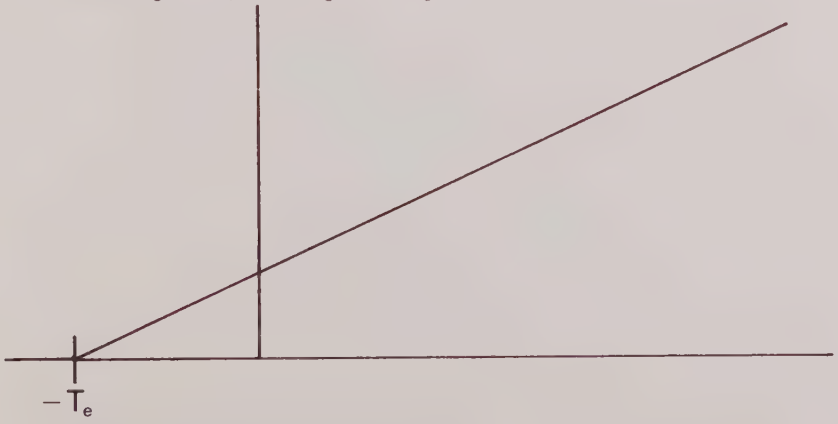
EFFECTIVE INPUT NOISE TEMPERATURE

A source temperature assigned to all accessible input ports of a noiseless equivalent transducer which would produce the same noise power at the output port as the actual transducer when the source termination is noiseless.

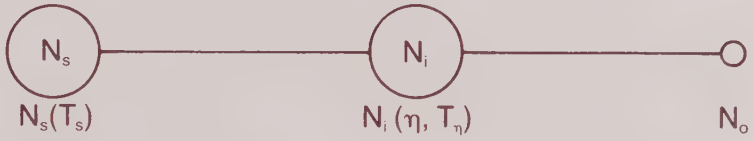




Let $N_o = O$, then $T_s = -T_e$



NOISE FIGURE OF A LOSSY ELEMENT



Earlier we saw:

$$N_o = \eta k T_s B + (1-\eta)\, k T_\eta B$$

For the Ideal, Noiseless Transducer:

$$T_\eta = 0$$

Therefore:

$$F = \frac{N_{Act}}{N_{Ideal}} \quad \Big| \quad T_s = T_o$$

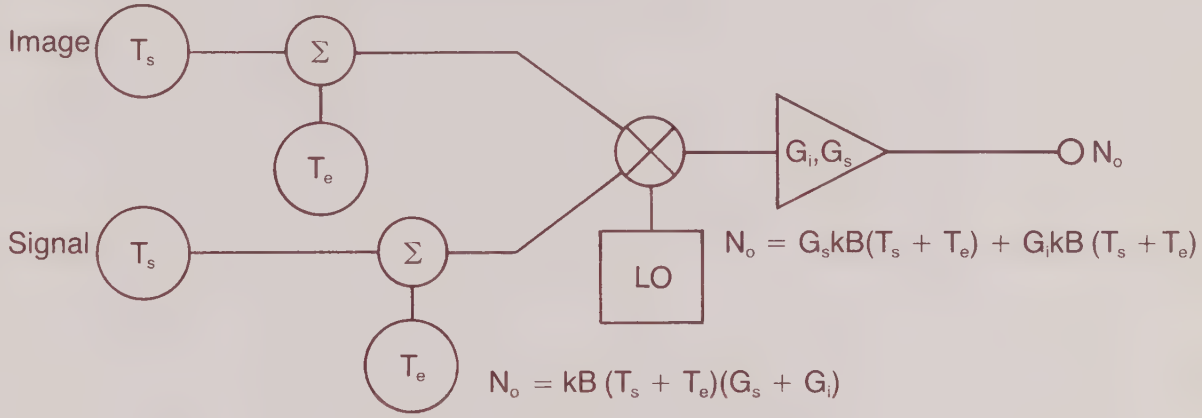
$$F = \frac{\eta k T_o B + (1-\eta) k T_\eta B}{\eta k T_o B}$$

If $T_\eta = T_o$

$$F = \frac{1}{\eta} = \text{Loss}$$

SOME COMPLICATIONS– IMAGE RESPONSE

Given— A heterodyne system:



For most typical situations, the signal will occupy only one channel (excludes radio astronomy).

$$F = \frac{N_{Act}}{N_{Ideal}} \quad \Big| \quad T_s = T_o$$

$$F = \frac{kB(T_o + T_e)(G_s + G_i)}{kBG_sT_o}$$

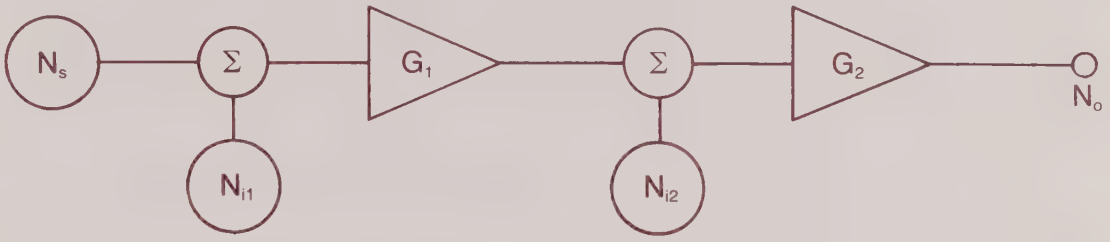
$$F = \left(\frac{T_e}{T_o} + 1\right)\left(1 + \frac{G_i}{G_s}\right)$$

NOTE: The noise figure of a noiseless *heterodyne* receiver can never be less than $\left(1 + \frac{G_i}{G_s}\right)$

$$F > \left(1 + \frac{G_i}{G_s}\right)$$

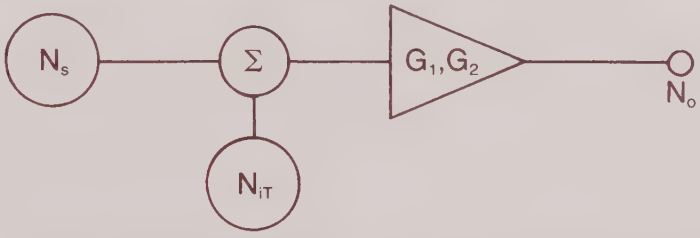
MORE COMPLICATIONS– SECOND STAGE NOISE

Given—A cascade amplifier system.



$$N_o = G_2 N_{i2} + G_2 N_{o1}$$
$$= G_2 N_{i2} + G_1 G_2 N_{i1} + G_1 G_2 N_s$$

EQUIVALENT SINGLE TRANSDUCER



$$N_o = G_1 G_2 N_{iT} + G_1 G_2 N_s = G_2 N_{i2} + G_1 G_2 N_{i1} + G_1 G_2 N_s$$

$$N_{iT} = \frac{N_{i2}}{G_1} + N_{i1}$$

$$N_{iT} = (F_T - 1)\, T_o, \qquad N_{i2} = (F_2 - 1)\, T_o, \qquad N_{i1} = (F_1 - 1) T_o$$

$$F_T = F_1 + \frac{F_2 - 1}{G_1}$$

$$T_{eT} = T_{e1} + \frac{T_{e2}}{G_1}$$

1st stage really effects the net noise figure

Can be easily extended to more stages.

SECOND STAGE NOISE—BANDWIDTH EFFECTS

The standard cascade relation:

$$F_T = F_1 + \frac{F_2 - 1}{G_1}$$

holds only if,

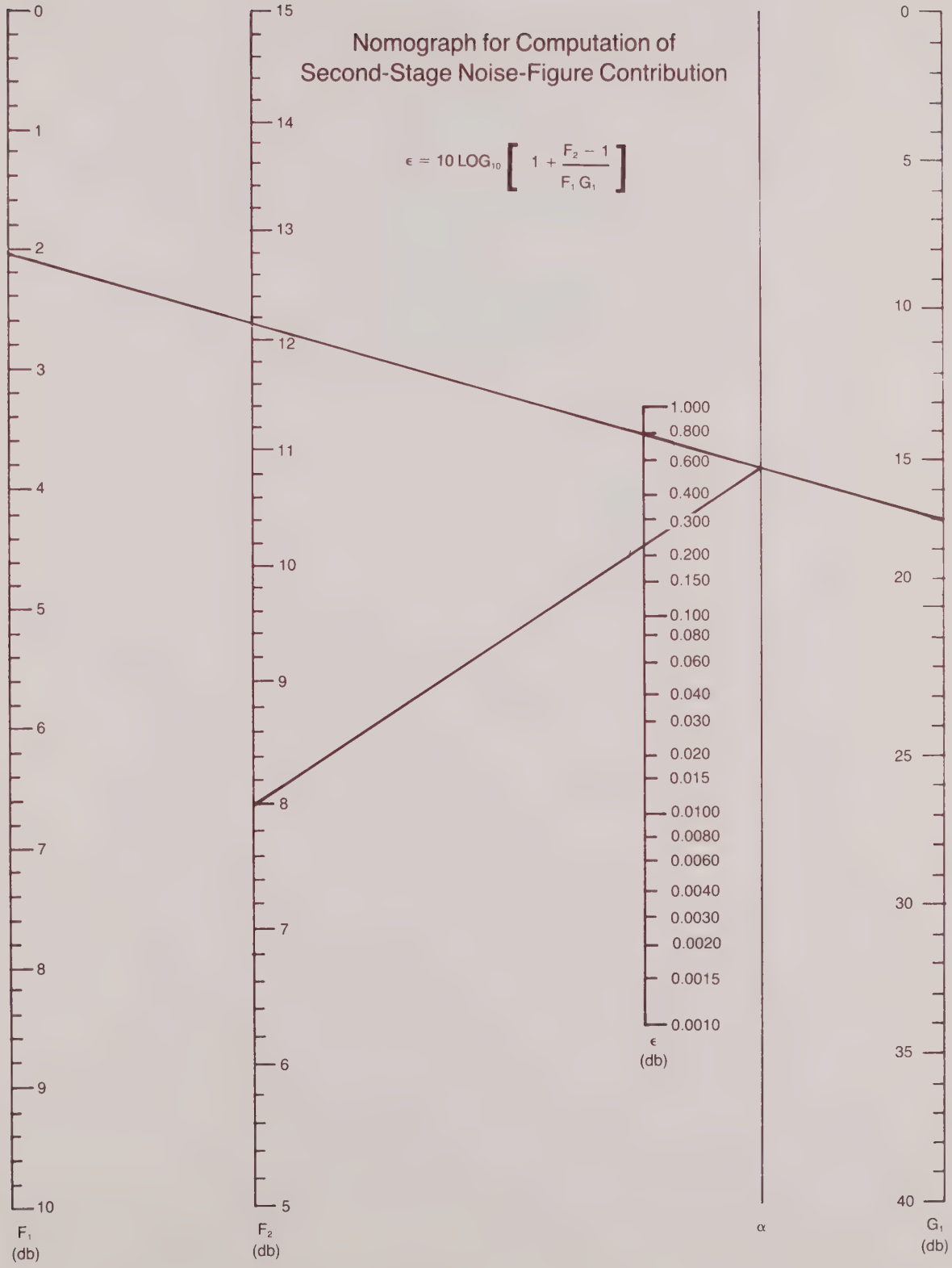
$$B_1 \geqq B_2$$

If, however:

$$B_1 < B_2$$

Then,

$$F_T = F_1 + \left(\frac{F_2 - 1}{G_1} \right) \left(\frac{B_2}{B_1} \right)$$

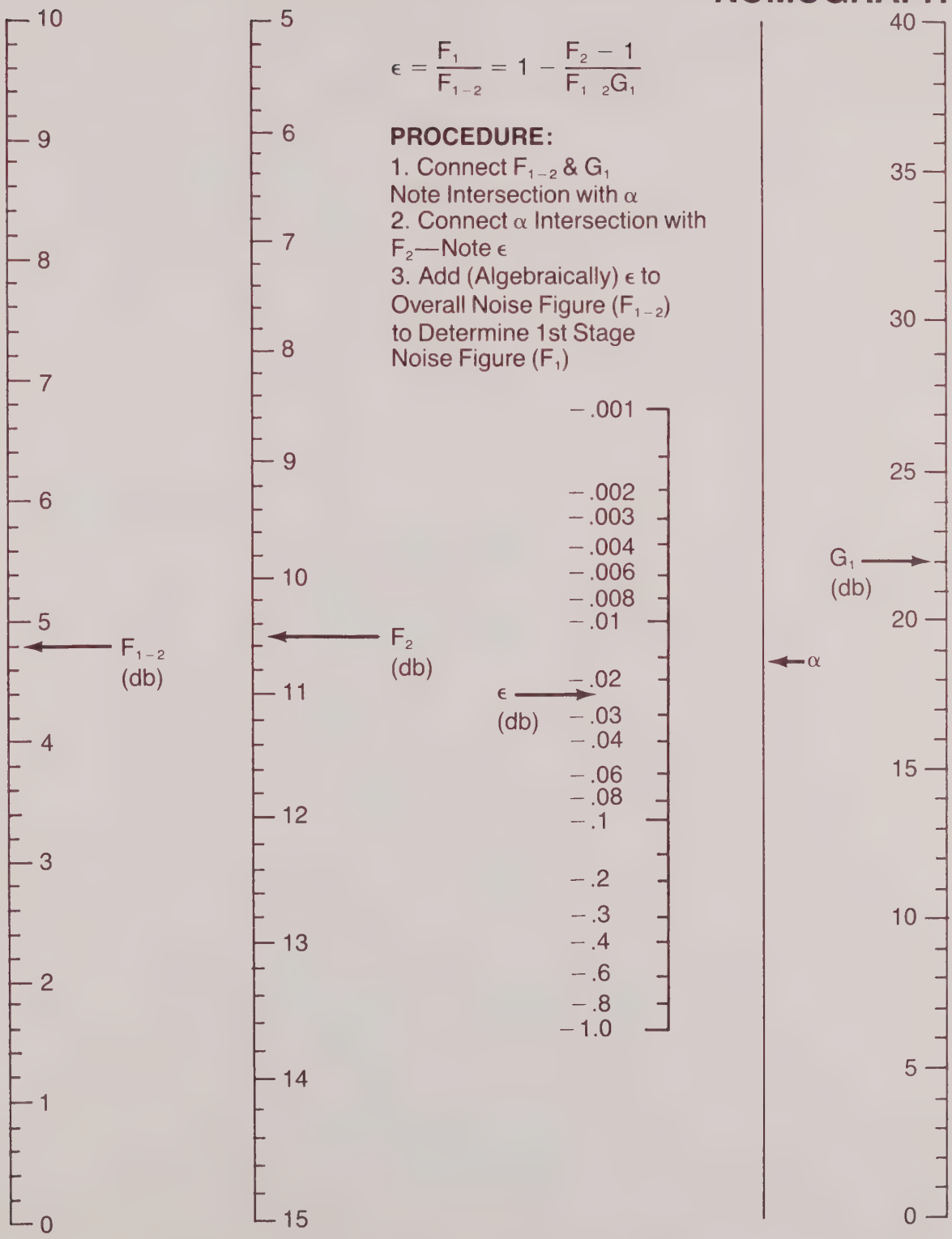

Nomograph for Computation of
Second-Stage Noise-Figure Contribution
$\epsilon = 10 \log_{10} \left[1 + \frac{F_2 - 1}{F_1 G_1} \right]$
0
1
2
3
4
5
6
7
8
9
10
F_1 (db)
15
14
13
12
11
10
9
8
7
6
5
F_2 (db)
1.000
0.800
0.600
0.400
0.300
0.200
0.150
0.100
0.080
0.060
0.040
0.030
0.020
0.015
0.0100
0.0080
0.0060
0.0040
0.0030
0.0020
0.0015
0.0010
ϵ (db)
α
0
5
10
15
20
25
30
35
40
G_1 (db)

NOMOGRAPH

$$\epsilon = \frac{F_1}{F_{1-2}} = 1 - \frac{F_2 - 1}{F_1 \; {}_2G_1}$$

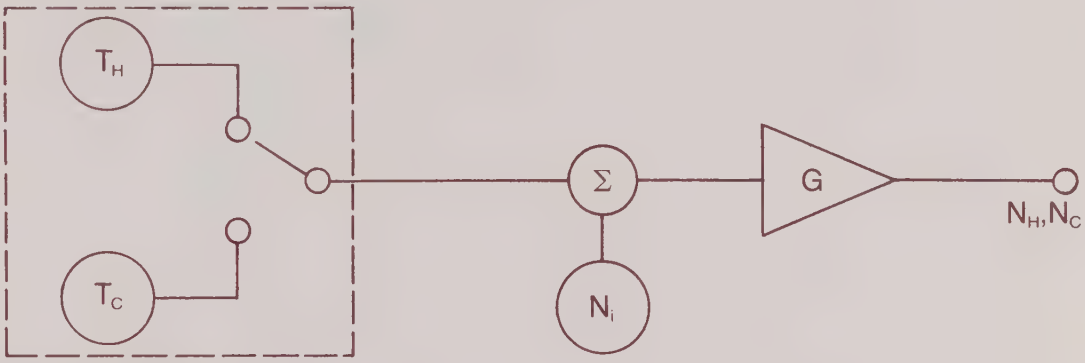
PROCEDURE:

1. Connect F_{1-2} & G_1 Note Intersection with α
2. Connect α Intersection with F_2—Note ϵ
3. Add (Algebraically) ϵ to Overall Noise Figure (F_{1-2}) to Determine 1st Stage Noise Figure (F_1)



NOISE MEASUREMENT

General: Y-factor technique.



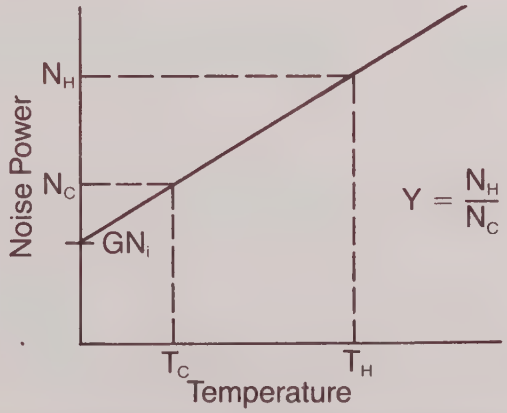
Noise Generator

$$Y = \frac{N_H}{N_C} = \frac{GkT_HB + GN_i}{GkT_CB + GN_i}$$

$$Y = \frac{GkB\,[T_H + (F-1)\,T_o]}{GkB\,[T_C + (F-1)\,T_o]} = \frac{GkB\,(T_H + T_e)}{GkB\,(T_C + T_e)}$$

$$F = \frac{\frac{T_H}{T_O} - Y\frac{T_C}{T_O}}{Y - 1} + 1$$

$$T_e = \frac{T_H - YT_C}{Y - 1}$$



If T_C and T_H are known, measurement of Y allows calculation of all noise parameters.

EXCESS NOISE RATIO

Another expression for noise figure

$$F = \frac{\left(\frac{T_H}{T_O} - 1\right) - Y\left(\frac{T_c}{T_O} - 1\right)}{Y - 1}$$

If $T_C = T_O$ (290 K)

$$F = \frac{\frac{T_H}{T_O} - 1}{Y - 1}$$

$$\text{EXCESS NOISE RATIO (ENR)} = \frac{T_H}{T_O} - 1$$

$$F_{dB} = ENR_{dB} - 10LOG_{10}(Y - 1)$$

Often used when the noise generator T_C is room temperature.

This causes an error—the magnitude is a function of measured noise figure, ENR, and T_C deviation from T_O.

The error is significant only when measuring low noise figures or at significant temperature deviations.

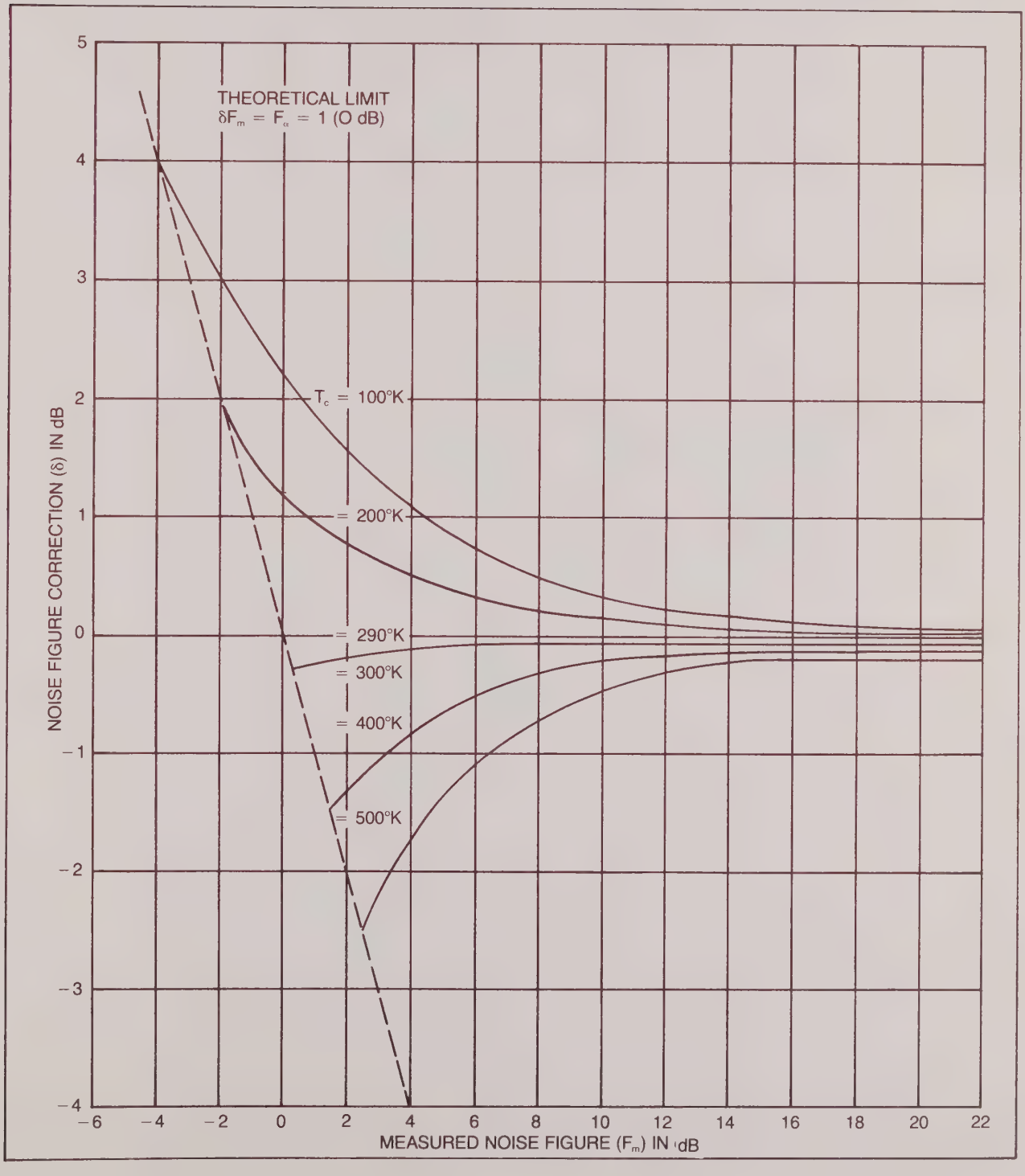
For example:

If $T_C = 300$ K (+ 27°C, 81°F) and the measured noise figure = 2 dB.

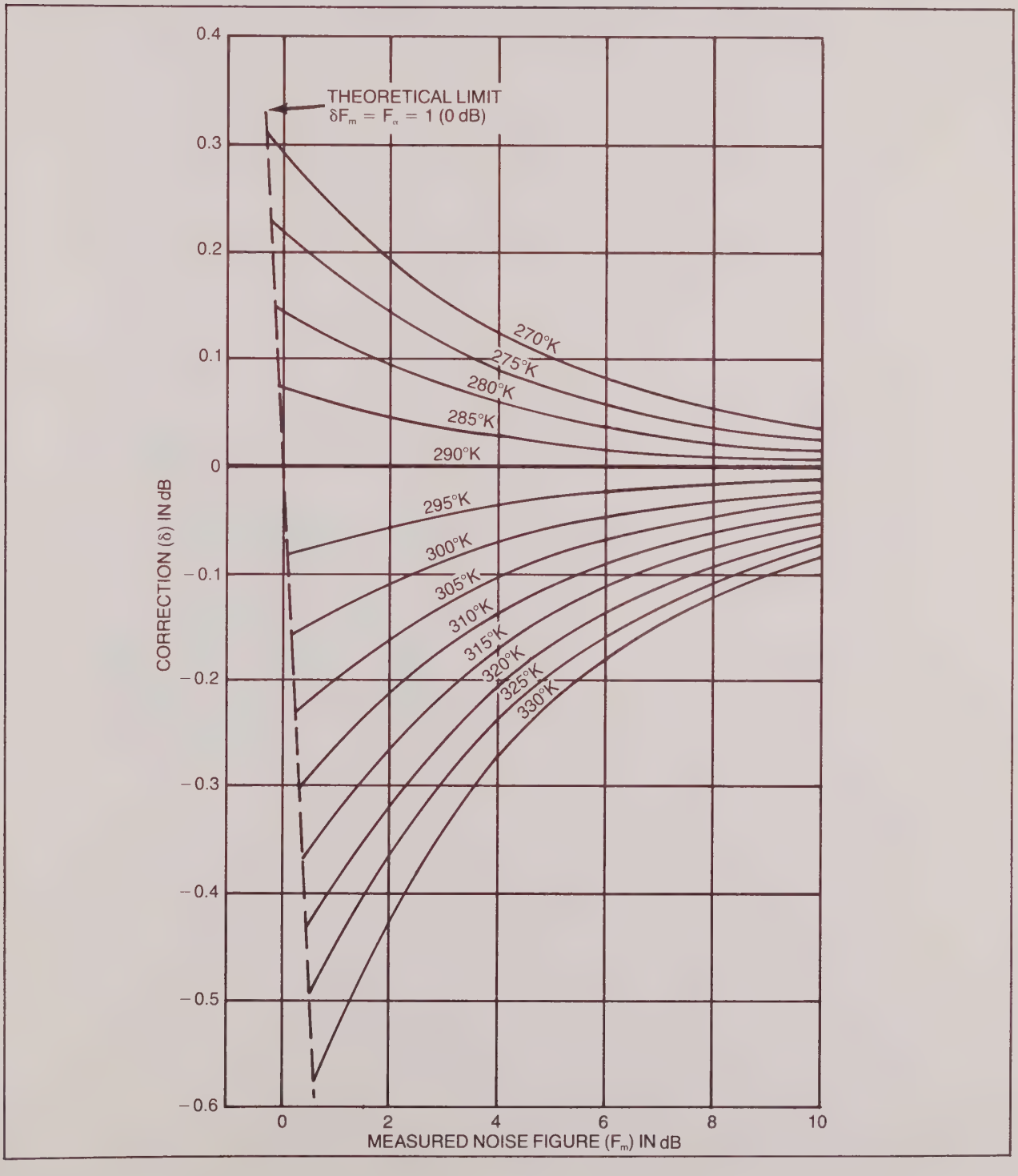
The error = + 0.1 dB.

The error decreases at higher noise figures.

TERMINATION TEMPERATURE ERROR



TERMINATION TEMPERATURE ERROR



SUMMARY

- Noise figure is a unique, valid measure of the noise performance of an amplifier or receiver.

- Noise figure can be easily determined by measuring the *RATIO* of the UUT output noise powers under two known source termination conditions (temperature).

- The measurement can be complicated by:
  - Existence of an image response.
  - Second-stage noise.
  - Cold source temperature deviations from T_O.
  - Loss between the noise generator and the UUT.

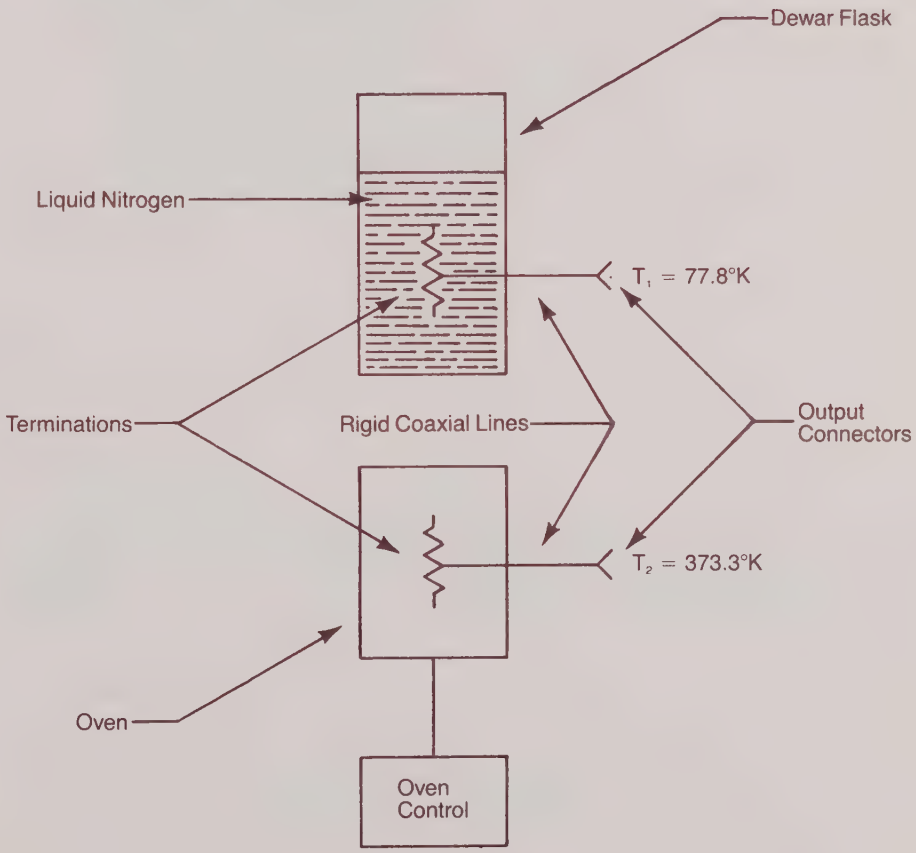
PRACTICAL MEASUREMENT TECHNIQUES

- MODERN NOISE GENERATORS
- MANUAL Y-FACTOR I.F. SUBSTITUTION
- DIRECT-READING I.F. INSTRUMENTATION
- THE DIGITAL MACHINE—ELIMINATING THE COMPLICATIONS

NOISE GENERATORS

THE THREE BASIC TYPES IN GENERAL USE TODAY

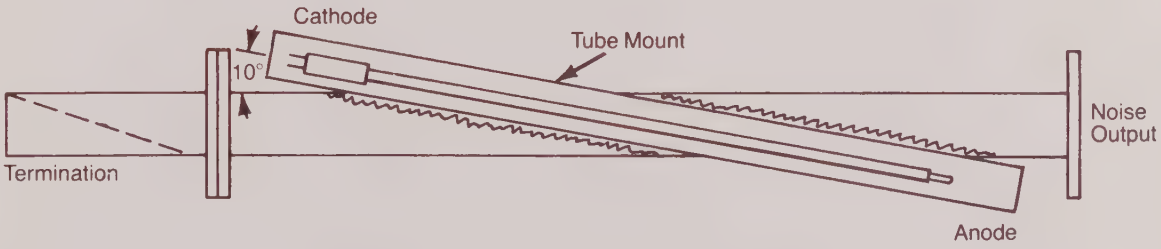
- Thermal (Hot-Cold Terminations)
  - Very Accurate
  - Low SWR/SWR Variation
  - Inconvenient – Liquid Nitrogen Required
    – Two Connections



SCHEMATIC REPRESENTATION OF A
TYPICAL THERMAL NOISE SOURCE

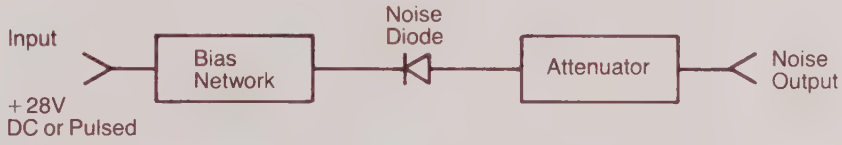
- Waveguide Gas-Discharge
  - Stable with Power Source
  - Flat with Frequency
  - Significant Mismatch Change On to Off
  - High Voltage Power Supply Required
  - Cold Termination Heating

Only Consistently Repeatable Sources Above 26 GHz.

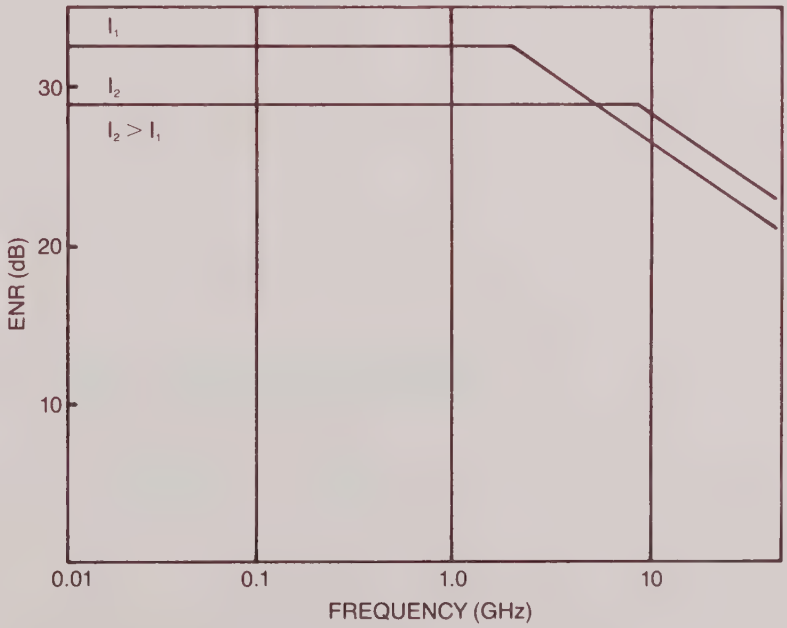


Waveguide Gas-Discharge
Noise Generator

- Solid State Noise Generators
  - Very Wide Frequency Range (10 MHz to 26 GHz)
  - Low SWR—Low On-Off Variation
  - Low Power Dissipation
  - Negligible Cold Termination Heating
  - Requires High-Stability Power Supply
  - Requires Calibration with Frequency (ENR Variation)

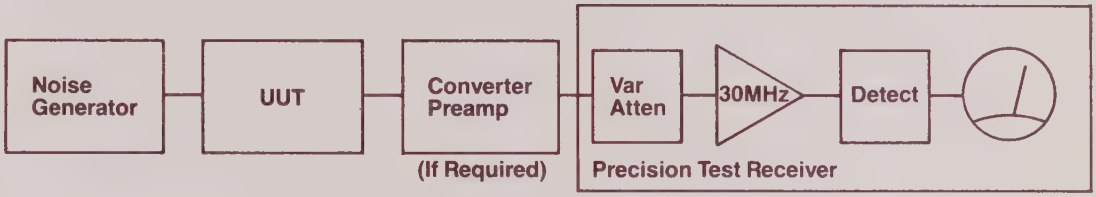


Block Diagram of a Typical Solid-State Noise Generator for Laboratory Use



ENR vs Frequency at Two Diode Current Levels (Diode Only)

MANUAL Y-FACTOR: I.F. SUBSTITUTION



When the UUT includes the downconverter, 2nd stage correction is not required.

Y-Factor measurement is directly related to a primary physical parameter (diameter of a circular waveguide).

Potentially the most accurate measurement when used with a hot-cold since T_H, T_C, and Y can be directly traced to primary physical parameters.

Often used as the "final arbiter" to resolve differences between direct reading measurement systems.

MEASUREMENT UNCERTAINTY

Noise figure is calculated from:

$$F = \frac{\frac{T_H}{T_O} - Y\frac{T_C}{T_O}}{Y - 1} + 1$$

$$F_{dB} = 10\,LOG_{10}\,F$$

The primary instrumentation uncertainty is given by:

$$\Delta F = \left|\frac{\delta F}{\delta T_H}\right|\Delta T_H + \left|\frac{\delta F}{\delta T_C}\right|\Delta T_C + \left|\frac{\delta F}{\delta Y}\right|\Delta Y$$

$$\Delta F_{dB} = 4.34\,\frac{\Delta F}{F}$$

NUMERICAL EXAMPLE

$F_{dB} = 2\ dB,\ T_H = 373K,\ T_C = 78K$

$Y_{dB} = 3.4\ dB$

$\Delta T_H = \Delta T_C = \pm\ 1K$

$\Delta Y_{dB} = \pm\ 0.04\ dB$

TAKING THE DERIVATIVES:

$$\Delta F = \frac{\Delta T_H}{T_O} + \frac{Y \Delta T_C}{T_O} + \frac{(T_H - T_C)\,\Delta\, Y}{T_O\,(Y-1)^2}$$

SUBSTITUTING VALUES:

$\Delta F|_{\Delta T_H} = 0.003$

$\Delta F|_{\Delta T_C} = 0.008$

$\Delta F|_{\Delta Y} = 0.015$

ADDITIVE SUMMATION (WORST CASE)

$\Delta F = \pm\ 0.026$

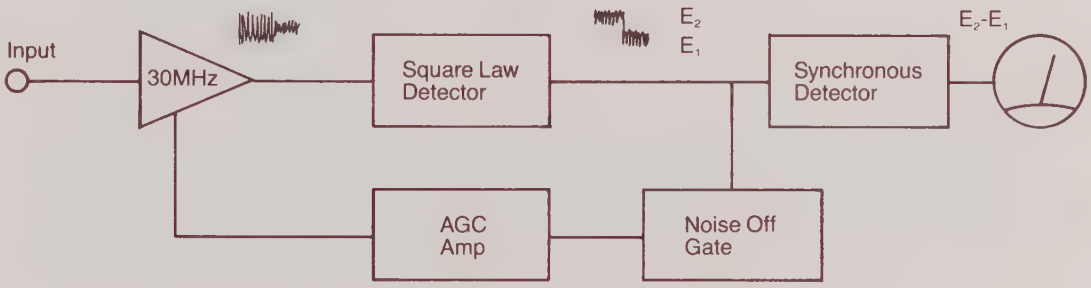
$\Delta F_{dB} = \pm 0.07\ dB$

DIRECT READING I.F. INSTRUMENTATION

Basically, analog computing instruments.

Until recently, the most accurate direct-reading instruments.

AILTECH 7514 BLOCK DIAGRAM



$V_M = E_2 - E_1$

E_1 = Constant due to AGC

$$V_M = A\left(\frac{E_2}{E_1} - 1\right).$$

With Square-Law Detection

$V_M = B\,(Y - 1)$

$$V_M = B\frac{ENR}{F}$$

Could not correct for 2nd stage noise.

Could not correct for $T_C \neq T_O$.

7300 SERIES

1st Bus-compatible instruments.

1st Simultaneous noise and gain measurements.

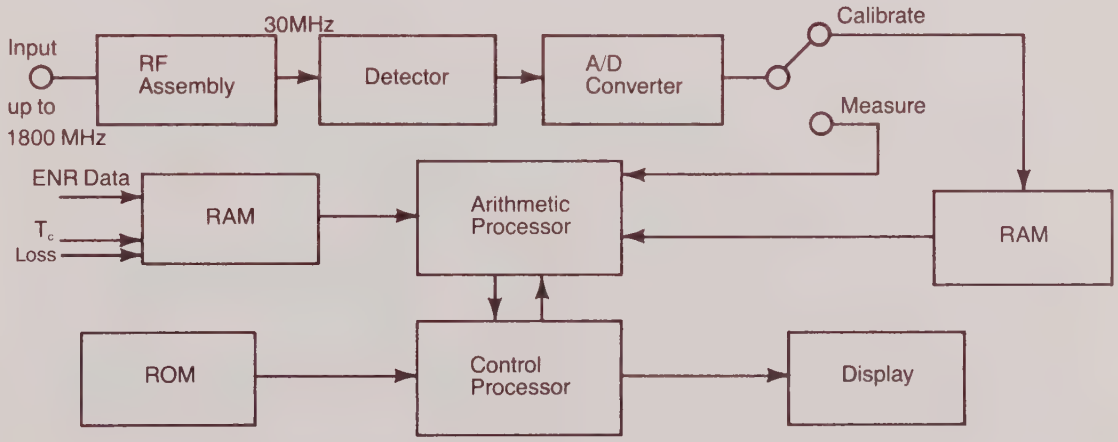
Could compensate for 2nd stage, image, and T_C when mated to a computer.

The forerunner to the AILTECH 2075.

Eliminating the complications

- Image Response
- T_C Error
- 2nd Stage Error
- ENR Variations
- Loss Preceeding UUT

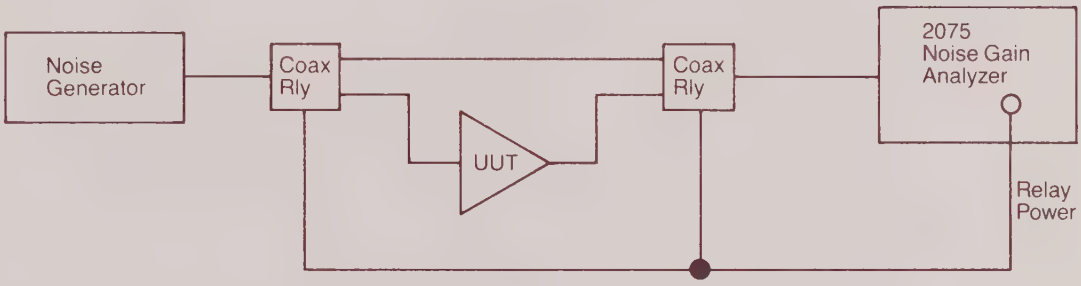
Over the past few years there have been significant improvements in the performance and cost of up/down converters originally designed for spectrum analyzers. This technique, in conjunction with extremely linear detection circuits, low-drift A/D converters, and high speed digital processors gave rise to a whole new concept in noise parameter measurement.



The 2075 keys the noise generator on and off, measures N_H and N_C and calculates F, Te, F_{dB}, Y, Y_{dB}, etc.

Thus, T_C, Loss and ENR variations are removed by application of the input data.

CORRECTING FOR 2ND STAGE EFFECTS



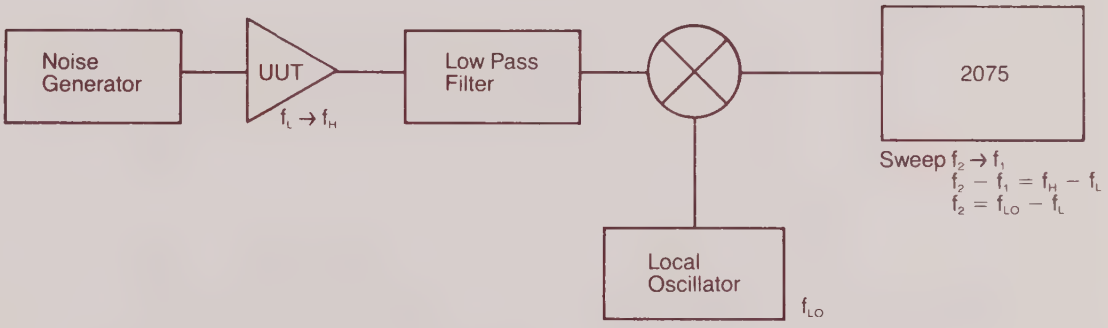
STEP 1. Connect the 76XX directly to the 2075 input.
2. Measure the 2075 over the selected frequency band (results are stored).
3. Insert the UUT—repeat the sweep.
4. Noise figure results are automatically corrected for F_2!

The 2075 is sufficiently sensitive to measure its own noise performance—it can even measure lossy devices.

Now we've eliminated three of the four complications, but what about image response?

We can use the same techniques as in the past—but with a high, I.F. many image response problems can be circumvented.

SWEPT I.F.

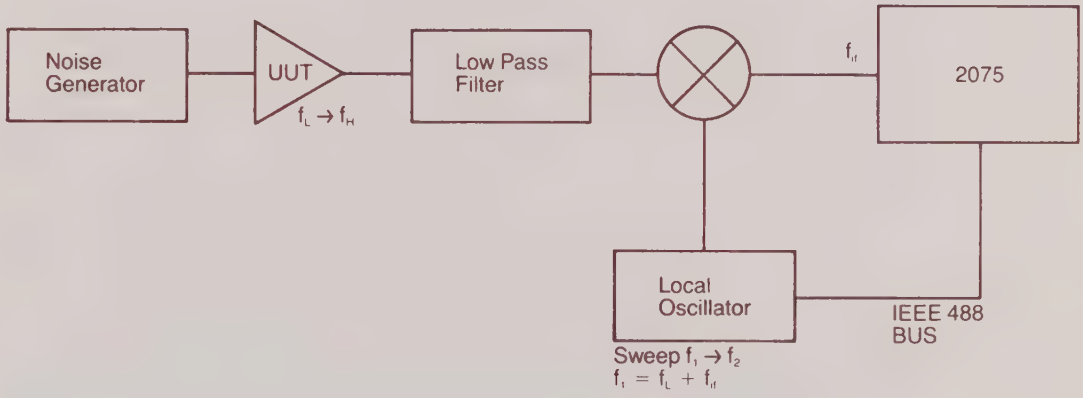


SOME TYPICAL FREQUENCY PLANS

UUT FREQUENCY	LOCAL OSCILLATOR FREQUENCY	2075 INPUT FREQUENCY	IMAGE FREQUENCY
1 to 2 GHz	2.8 GHz	1.8 to 0.8 GHz	4.6 to 3.6 GHz
3.7 to 4.2 GHz	5.0 GHz	1.3 to 0.8 GHz	6.3 to 5.8 GHz
5.9 to 6.4 GHz	7.4 GHz	1.5 to 1.0 GHz	8.9 to 8.4 GHz

The filter is required to be consistently singe sideband in both calibration and measurement modes.

MICROWAVE MEASUREMENTS
SWEPT LOCAL OSCILLATOR

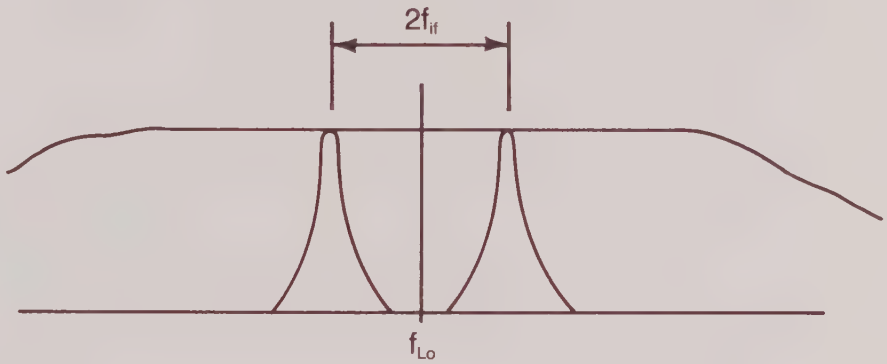


Again the high I.F. helps get rid of the image.

The filter can be eliminated for double sideband measurements.

DOUBLE OR SINGLE SIDEBAND—WHEN?

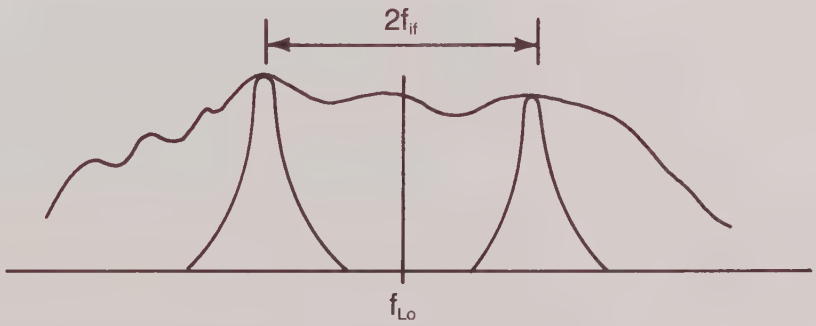
For swept measurements over very broad ranges—



1. $2f_{if} \ll f_{Lo}$
2. Response essentially flat over $\triangle f = 2f_{if}$

DSB is simpler to implement (no filter required).

For swept measurements over narrow ranges—
and/or with significant difference between image and signal response—



SSB can be more accurate & less expensive to implement

MEASUREMENT UNCERTAINTY

MAJOR CONTRIBUTORS

- INSTRUMENTATION
  - ANALYZER READING ACCURACY
  - NOISE GENERATOR ENR ACCURACY
- MISMATCH
  - PRIMARY (NOISE GENERATOR/UUT)
  - SECONDARY (NOISE GENERATOR/ANALYZER, UUT/ANALYZER)
- CORRECTION ACCURACY
  - 2nd STAGE NOISE
  - COLD TERMINATION TEMPERATURE
- TECHNIQUE AND PROCEDURE
  - INTERFERENCE (EXTERNAL SOURCES)
  - CONNECTOR INTEGRITY (WEAR AND CARE)
  - CONSISTENT CONNECTION (CONNECTOR TORQUE)
  - LOSS CORRECTION
  - UUT LINEARITY (AGC OR LIMITING)

ANALYZER ACCURACY

- BASED ALMOST ENTIRELY ON LINEARITY.

  OPTIMIZED BY ADJUSTING THE SIGNAL LEVEL TO FALL WITHIN THE MOST LINEAR REGION OF THE DETECTOR.

  ±0.05 dB (F_{dB} <12 dB)
  ±0.1 dB (F_{dB} >12 db)

- VERIFIED BY MANUAL I.F. ATTENUATION SUBSTITUTION (Y-FACTOR).

NOISE GENERATOR ENR UNCERTAINTY

All AILTECH noise generators are calibrated using the AILTECH 82 Noise Calibration System.

This system has been reviewed by the U.S. National Bureau of Standards.

The 82 System can resolve ENR differentials as small as 0.005 dB and uses a manual tuning system that significantly reduces mismatch uncertainty.

ENR CALIBRATION UNCERTAINTY (± dB)

	Worst Case	Root Sum Squares
*Primary Standard (NBS)	0.060	0.060
Mismatch	0.030	0.018
82 System Uncertainty	0.025	0.021
Adapter Loss Uncertainty	0.030	0.030
*Working Standard	0.145	0.073
Mismatch	0.030	0.018
82 System Uncertainty	0.025	0.021
*Production Noise Generator (Specified at ± 0.25 dB)	0.200	0.078

THE UNCERTAINTY EQUATION

$$F_1 = F_T - \frac{F_2 - 1}{G_1}$$

$$\Delta F_1 = \frac{\delta F_1}{\delta F_T}\Delta F_T + \frac{\delta F_1}{\delta F_2}\Delta F_2 + \frac{\delta F_1}{\delta G_1}\Delta G_1$$

Also, $F_{dB} = 10\,LOG_{10}F$

$$\Delta F_{dB} = 4.34\frac{\Delta F}{F}$$

Then,

$$\Delta F_{1dB} = \frac{F_T}{F_1}\ \Delta F_{TdB} - \frac{F_2}{F_1G_1}\Delta F_{2dB} + \frac{F_2 - 1}{F_1G_1}\ \Delta G_{1dB}$$

Be careful with the use of the second term. One component of both ΔF_T and ΔF_2 may or may not be correlated. This is the ENR term.

If the UUT includes frequency translation, the first two terms are uncorrelated, and the *magnitudes* should be summed (or RSS'd).

If the input and output frequencies of the UUT are the same, the ENR uncertainties contributing to ΔF_T and ΔF_2 are correlated. They should be extracted and a fourth term added:

$$\left|\frac{F_T}{F_1} - \frac{F_2}{F_1G_1}\right| \Delta\,ENR$$

UNCERTAINTY CONTRIBUTORS

ΔF_T

Analyzer
Mismatch—Noise Generator/UUT Input
ENR—Frequency Translators Only

ΔF_2

Analyzer
Mismatch—Noise Generator/2nd Stage Input
ENR—Frequency Translators Only

ΔG_1

Analyzer
Mismatch—Noise Generator/UUT Input
Mismatch—Noise Generator/2nd State Input
Mismatch—UUT Output/2nd Stage Input
ENR—Frequency Translators Only

NOTE: Each Situation has to be Evaluated Individually; However, You can do a Summary Analysis Based on "Typicals."

SUMMARY EVALUATION—NOISE FIGURE

UUT: Microwave Amplifier
F_{1dB} = 6 dB, SWR (in and out) <1.5, G_{1dB} = 30 dB
Second Stage Noise Figure (F_2) = 10 dB
Source SWR<1.15

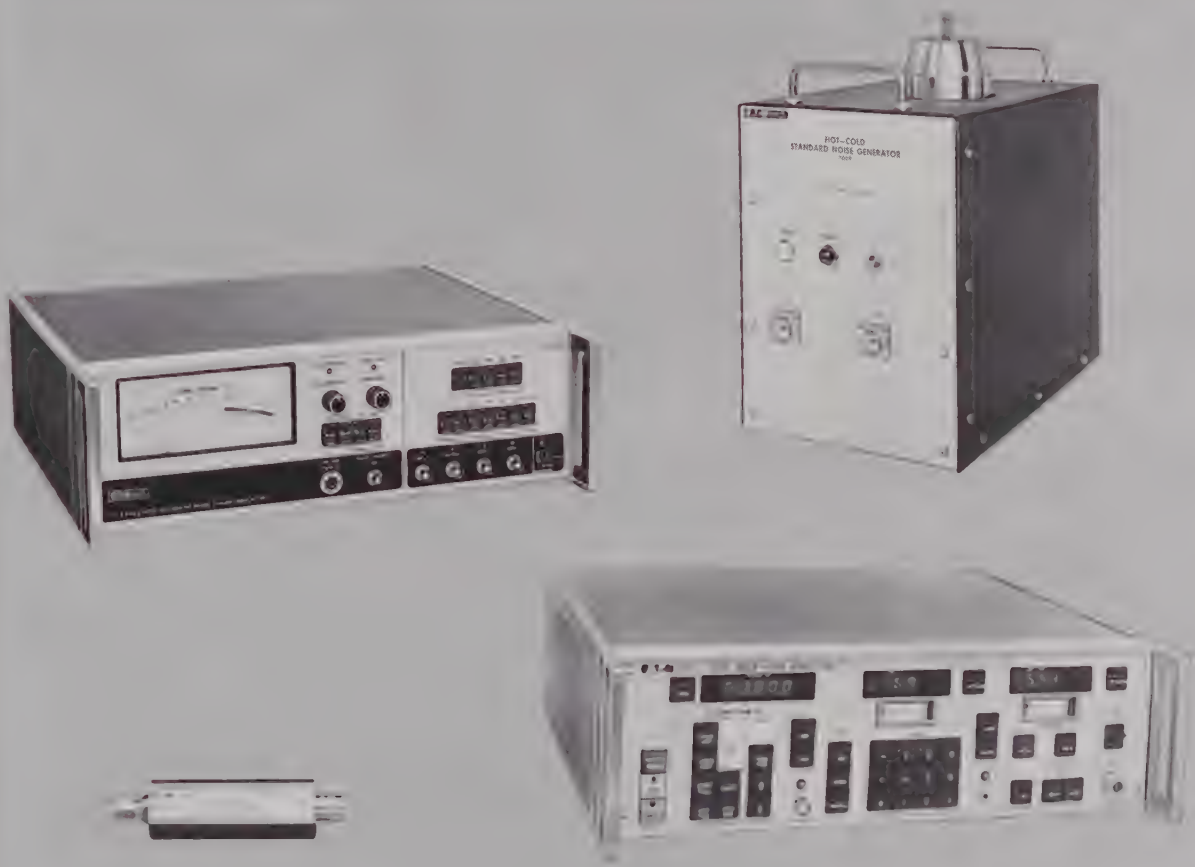
Since the UUT has Sizeable Gain, Only Residual Errors Associated with the Corrections Need Be Considered for 2nd Stage Effects and T_c.

	Worst Case	RSS
Analyzer	0.05	0.05
ENR	0.25	0.08
Mismatch	0.15	0.15
Second Stage	0.10	0.10
T_c	0.01	0.01
Overall Uncertainty	0.56 dB	0.20 dB

State of the art accuracy available today.

A Review of Noise Figure Instrumentation

William E. Pastori, Eaton Corporation
Electronic Instrumentation Div.
Los Angeles, CA



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EATON Advanced Electronics

A Review of Noise Figure Instrumentation

William E. Pastori

Eaton Corporation, Electronic Instrumentation Div., Los Angeles, CA

Introduction

A major — if not the primary — characteristic of modern RF and microwave receiving systems is the ability to extract intelligence from signals emanating from remote locations — in effect, sensitivity. The greater the distance traversed by the signal, the more stringent are the sensitivity requirements.

The sensitivity of such receivers is inherently limited by the electromagnetic noise generated within the receiver itself. This is particularly true for systems operating above HF where atmospheric and other external disturbances are less significant than at lower frequencies.

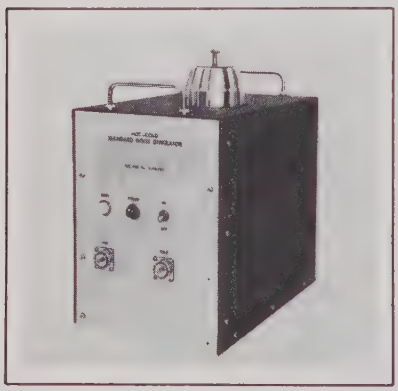


Fig. 1 Thermal noise generators such as the Eaton 7009 Hot-Cold Standard Noise Generator pictured above are often used as laboratory noise standards at lower frequencies.

Noise figure (and the associated parameter, effective input noise temperature) is a unique measure that provides a means of evaluating the internal noisiness of receiver systems and the sub-elements (amplifiers, mixers, etc.) that go to make up the system.

The concept of noise figure is applicable to the individual system components as well as the overall receiver. It provides a common language that permits prediction of overall system performance from the specifications of individual receiver sub-elements and conversely provides a means of specifying the noise performance of these components to meet an overall system noise criterion.

Theory and Definitions

Noise in receiving systems is usually characterized in terms of the noise power available from a thermal source — a resistive termination; i.e.,

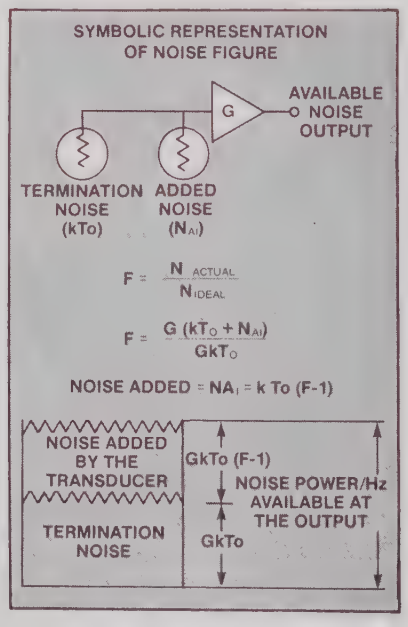
$$P_N = kT \qquad (1)$$

where P_N = available noise power per unit bandwidth

k = Boltzmann's constant (1.38×10^{-23} joules/°K)

T = temperature of the source expressed in °K

Noise figure can be defined (in simplified form) as the ratio of the actual noise output power of a transducer (receiver, amplifier, etc.) to that of an ideal noiseless transducer of otherwise identical characteristics when both are terminated at the input by a resistive source at 290°K (the standard reference temperature, T_O). It is a measure of the amount of noise added by the transducer to the termination noise. This is shown symbolically in the accompanying box.



At this point, it should be noted for the more serious minded that the preceding is a highly simplistic representation deliberately abridged, for purposes of this article, to provide a basic introduction to the concept of noise figure. Noise powers are expressed per unit bandwidth and effects of image response are not considered to prevent this introduction from becoming unduly lengthy and complicated. A full treatment of the subject can be found in Reference 1.

Measurement Concept

The concepts involved in noise figure measurements are, on the surface, quite simple; however, all precautions normally associated with RF and microwave measurements (mismatch, measurement system linearity, etc.) should be observed. In addition, there are some difficulties somewhat unique to this particular discipline.

Noise figure measurements generally reduce to a comparison of RF or microwave powers. Those in the metrology field are well aware of the associated accuracy problems. Add to this that the comparison is usually at very low power levels: a microwave amplifier with 10 dB gain and 3 dB noise figure will have a noise power output of -101 dBm in a 1 MHz bandwidth.

Another factor to be considered is the composition of the signal itself. Although noise can be characterized in terms of an average power (or power spectral density), it is truly random — at any instant of time the signal can take

on any value between plus or minus infinity. Circuit elements designed for more easily mathematically definable signals may react differently in the presence of noise — particularly with regard to amplitude linearity.

One of the early methods of evaluating noise figure involved measurement of the degradation of signal-to-noise ratio: the "signal generator" or "signal plus noise 3 dB" method. An increasing CW signal level was injected into the device under test until the output was equal to twice that when the device input was terminated in a passive load at 290 kelvins. Under this condition:

$$F = \frac{Si}{k\ T_o\ B} \qquad (2)$$

where, Si = input signal level
B = noise bandwidth of the UUT

As can be seen, this method depended upon the accuracy of the signal generator output level and required measurement of the noise bandwidth of the UUT.

The development of broadband, precision, random noise generators, and their refinement especially over the past two decades, eliminated these difficulties. Since the measurement involves taking a ratio, use of a stimulus with the same general spectral characteristics as the termination noise effectively eliminates bandwidth as a measurement factor.

Although variations did and still exist, the methodology that evolved is that commonly known as the Y-factor technique. All currently available noise figure instrumentation derive from this method. The Y-factor technique is illustrated in the insert (see box).

As can be seen, the method is an elegantly simple series attenuation substitution technique whose accuracy does *not* rely on the accuracy of a detector law (square-law, linear of something in between) or the linearity of the elements following the attenuator.

The primary elements insofar as instrumentation accuracy is concerned are the noise generator and the precision attenuator; the accuracy of both these devices can be related to directly measurable physical quantities, specifically: the physical temperature of a resistor and the diameter of a circular waveguide (assuming a waveguide-beyond-cutoff attenuator).

For these reasons, the manual implementation of the Y-factor method is most often used as the final determinant of UUT noise figure to resolve correlation problems between different direct-reading measurement systems, and as a means of calibrating direct-reading systems.

An obvious saving in time and convenience is offered by direct-reading instruments. In general, these automate the Y-factor method and eliminate the manually operated attenuator measuring Y-factor by some power-responsive means. Noise figure is then calculated and displayed either digitally or in some analog fashion. Some accuracy is usually sacrificed.

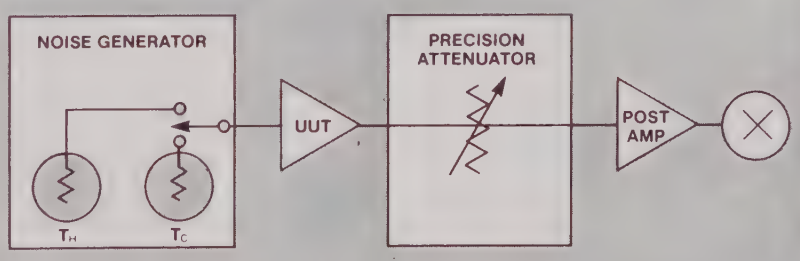
Noise Generators

The most popular, currently manufactured noise generators fall into three general categories based on the noise generating mechanism: thermal, gas-discharge, and solid-state. For the interested reader, a comprehensive, historical bibliography of noise generation techniques can be found in Reference 2.

The noise generating mechanism of a thermal noise generator is exactly what the name implies: a transmission line terminated with a resistive load, held in a constant thermal environment. The inherent simplicity of these devices make them the most accurate of the three types, and consequently, thermal noise generators are quite often used as calibration standards for gas-discharge and solid-state generators.[3]

Although some special purpose units using liquid helium have been built, liquid nitrogen is the most common environmental medium for commercially available cold noise sources due to its relative handling ease. Two commercially available coaxial thermal noise generators are illustrated in Figures 1 and 2. The construction of these instruments is generally similar — both consisting of a terminated coaxial line inserted through the side of a flask containing the liquid nitrogen. The Eaton 7009, which incorporates both a hot and cold termination, uses a vacuum DeWar, while the Maury

THE Y-FACTOR METHOD



- TERMINATE UUT INPUT IN T_C: NOTE OUTPUT INDICATION
- TERMINATE UUT INPUT IN T_H: INCREASE ATTENUATOR UNTIL THE OUTPUT RETURNS TO THE ORIGINAL INDICATION.
- NOTE THE REQUIRED ATTENUATION CHANGE: EXPRESS AS A DIMENSIONLESS RATIO GREATER THAN UNITY, SET EQUAL TO Y.

THEN,

$$N_o = kBGY\ [T_C + (F\text{-}I)\ T_O] = kBG\ [T_H + (F\text{-}I)\ T_O]$$

AND,

$$F = \frac{\left(\frac{T_H}{T_O} - 1\right) - Y\left(\frac{T_C}{T_O} - 1\right)}{Y - 1}$$

IF, $T_C = T_O$, $\left(\frac{T_H}{T_O} - 1\right)$ = EXCESS NOISE RATIO (ENR)

THEN, $F_{dB} = ENR_{dB} - 10\ Log_{10}\ (Y - I)$

Fig. 2 Waveguide and Coaxial Cooled Terminations up to 18 GHz offered by Maury Microwave. Maury also offers heated terminations with compatible temperature controls. (Photo courtesy of Maury Microwave, Cucamonga, CA.)

flask is foam-filled. Because of the extremely low temperatures involved (liquid nitrogen boils at about 78 kelvin — approximately 195 Celsius) both units provide a means of purging the cold transmission line of contaminants (primarily air and moisture) that might freeze and degrade the RF transmission characteristics of the line.

With a cold source temperature at 78 kelvin, very low noise measurements could be made using a room temperature termination as a hot noise source; however, in order to increase the Y-factor to a more measurable magnitude, many users prefer a hotter source. The Eaton unit pictured uses a termination, identical to the cold termination, inserted into an oven whose controlled temperature is calibrated against boiling water.

A major consideration in the accuracy of a noise figure measurement, regardless of the type of noise generator used, is the match presented to the UUT input by the source. Ideally, it should be a perfect match; however, of almost equal importance is the extent of mismatch change when the source is changed from the cold to the hot condition (a common failing of gas-discharge noise generators, somewhat less severe in solid-state units). Thermal noise generators, again because of conceptual simplicity, excel in this regard.

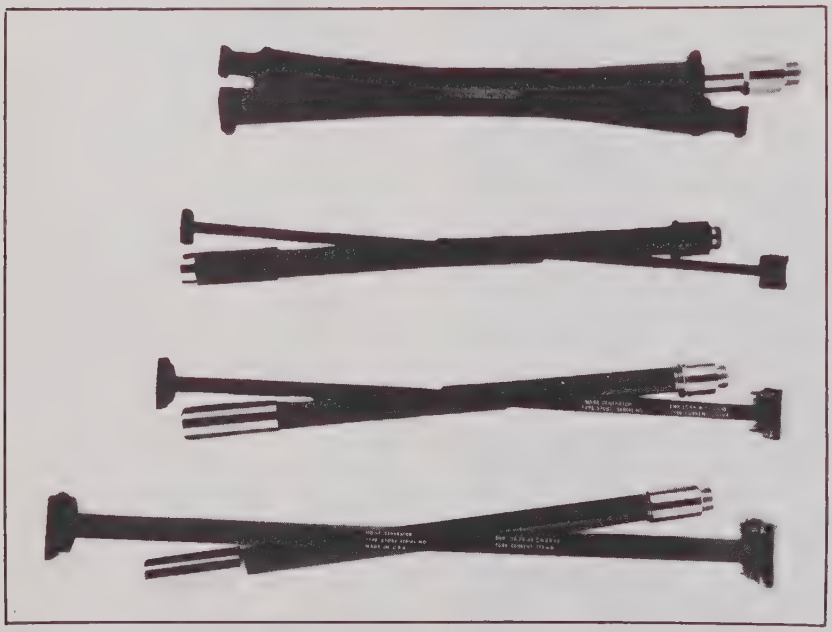


Fig. 3 Until recently, the most common means of generating noise above 18 GHz was through waveguide mounted, gas-discharge tubes. Pictured above is the Eaton 70 Series covering 8.2 to 40 GHz.

W. W. Mumford, then of Bell Laboratories, is generally credited with the development of the gas-discharge noise generator (4). Since the initial discovery of the broadband noise operating properties — extending well into the microwave region — of simple fluorescent light sources, the gas-discharge, noise generating tube has progressed to a mechanically precise, argon filled quartz tube with radioactive trace elements to ease ignition. The most common are cold cathode, although some hot-filament and indirectly heated types are still manufactured for standards use. C. P. Clare (Chicago, IL) produces the majority of gas-filled noise tubes in the United States. Nore Microwave (Southend-on-Sea, England) also manufactures precision tubes for standards and laboratory applications.

The most popular construction for laboratory applications consists of the slender, argon-filled tube inserted through the broad face (E-plane mount) of a length of waveguide at a shallow angle (typically 10°). The input waveguide is terminated at one end, and the UUT input is connected to the other. Figure 3 shows a typical unit manufactured by Eaton Corporation, Electronic Instrumentation Division. Other manufacturers of gas-discharge noise generators include C.P. Clare, Hewlett-Packard and Nore Microwave. The C. P. Clare offering includes units operating up to 110 GHz.

When the gas-discharge lamp

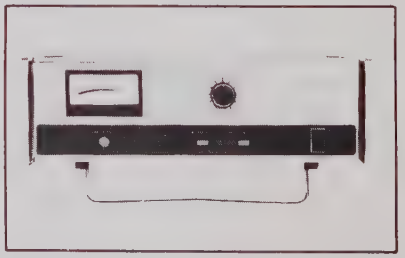


Fig. 4 The Eaton 7175 Gas-discharge Noise Generator Power Supply can operate as a stand-alone supply for manual Y-factor measurements or in synchronism with the 28 volt solid state noise generator drive available from most currently available noise measuring instruments.

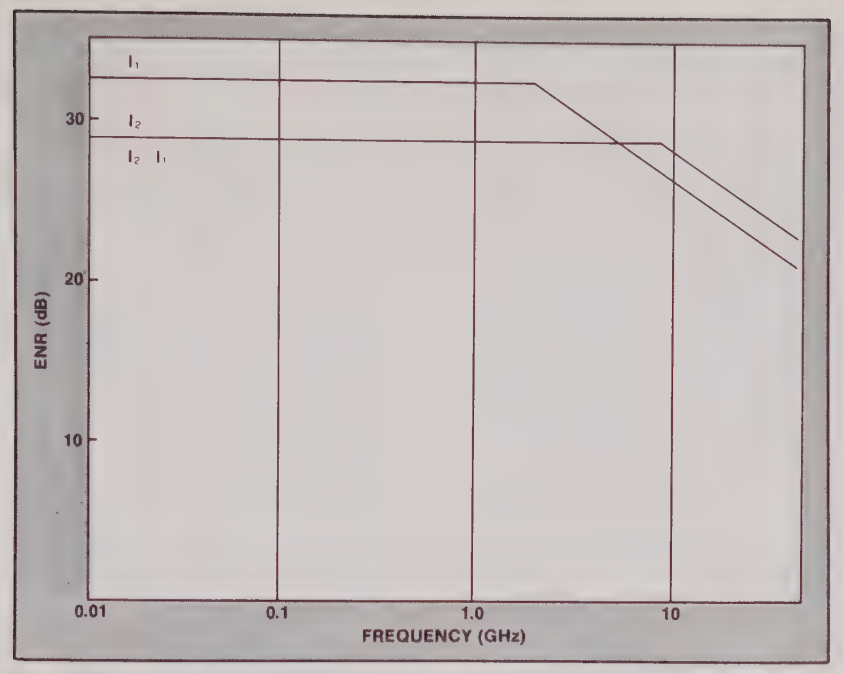


Fig. 5 Typical excess noise ratio (ENR) versus frequency performance of a solid-state noise diode at two different bias current levels.

is energized, the ionized gas becomes a good microwave absorber. Coupled with the shallow insertion angle, the configuration has the effect of a vane termination; however, the plasma represents a very hot termination electrically. The typical equivalent noise temperature at the output port of such units is about 11,000 kelvin (15.7 dB ENR). When the lamp is de-energized, the UUT is terminated by the passive load at the opposite end of the guide.

Waveguide gas-discharge noise generators have several positive features. They are relatively unaffected by temperature variations (exclusive of the effect on the passive termination) and operating current variations (typically 0.005 dB ENR change per milliamp of current change); both the tube and the mount are repeatable in manufacture; and the tube can be energized and de-energized in less than 100 microseconds so the noise generator can be used with most direct reading instrumentation systems.

The gas-discharge noise generator does, of course, have disadvantages. The most obvious is the voltage pulse required to initiate the discharge — typically, 1000 to 5000 volts peak, and the current required to sustain ionization — 100 to 200 ma. with a voltage drop of about 100 volts. The power supply required is, therefore, somewhat special.

Figure 4 shows the Eaton 7175, introduced in 1981, which is somewhat unique as such power supplies go, in that it features a trigger input designed to operate from the pulsed +28 volt output of most direct-reading instruments normally used to drive solid-state noise generators.

The power dissipation in a gas-discharge noise generator has a more subtle, deleterious effect on a noise figure measurement. After the device is turned on for a period of time, the power dissipation in the tube causes heat to be transferred to the passive "cold" termination, raising its temperature well above 290 kelvin, introducing a potentially significant error.

The disadvantages notwithstanding, and even given the availability of solid-state noise generators operating up to 40 GHz, many users still prefer gas-discharge units, particularly above 18 GHz, because of their known, proven repeatability. The present working standards at the U.S. National Bureau of Standards in three frequency bands are 9° E-plane mounts[5] and a variation of the NBS design is offered by Eaton Corporation for industrial standards laboratory use (Eaton 80 Series Noise Standards).

In general, however, most applications below 18 GHz utilize solid-state noise generators and, as always, frequencies of application go ever upwards.

It would be difficult to name any

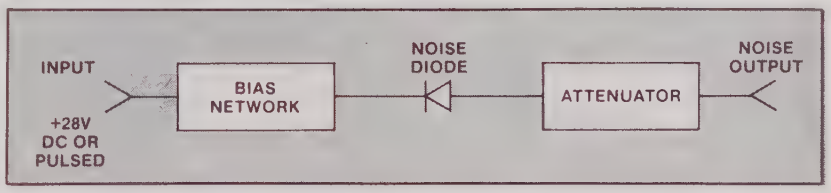


Fig. 6 Block diagram of a typical, commercial solid-state noise generator.

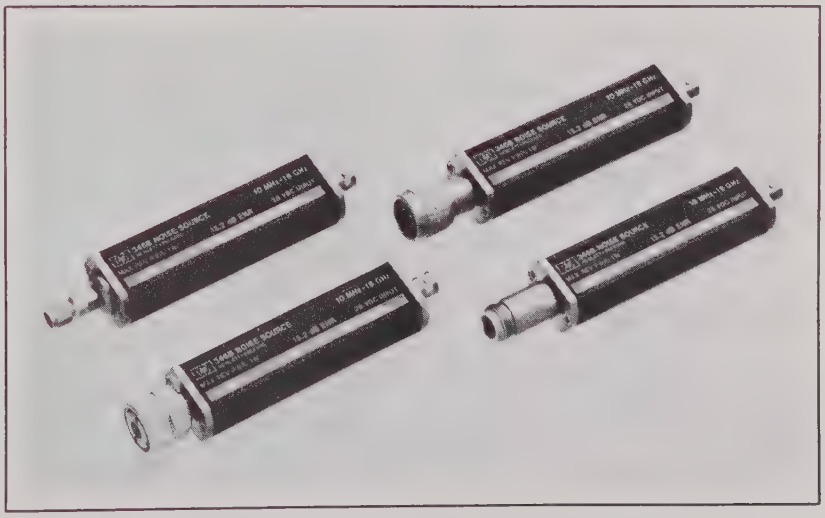


Fig. 7 The Hewlett-Packard Model 346B, 10 MHz to 18 GHz, Solid-State Noise Generator shown with various connector options. (Photo courtesy of Hewlett-Packard.)

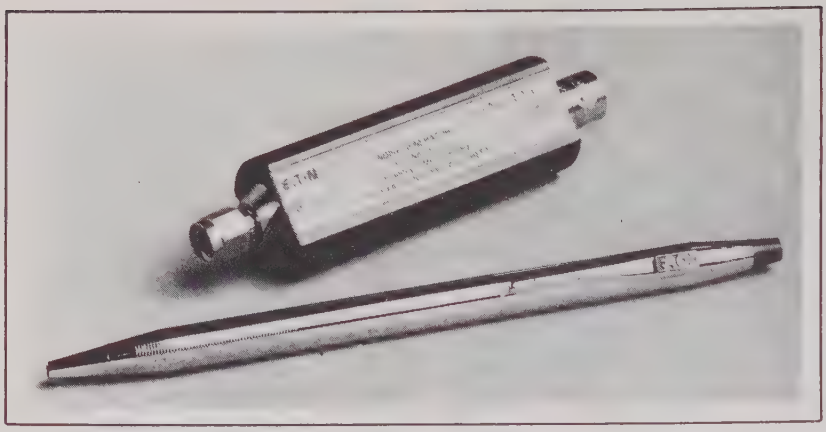


Fig. 8 The Eaton 7626, 10 MHz to 26 GHz, Solid State Noise Generator.

one individual responsible for the development of the solid-state noise generator based on the avalanche diode; however, it would be safe to say that every IF amplifier circuit designer in the early sixties that tried to use a zener diode as a local voltage regulator has observed the effect.

Under certain conditions, a semiconductor diode operated in the avalanche mode will generate a relatively large amount of RF and microwave noise (1×10^6 kelvin equivalent noise temperature is not uncommon). Figure 5 is an idealized plot of ENR versus frequency of a typical unit at several bias currents.

The high level of available noise power generated by the diode permits attenuation to be inserted between the device and the input of the UUT. The attenuator masks the rather severe source impedance change that would normally be seen as the diode is switched from the "on" to the "off" state. Figure 6 is a block diagram of the typical configuration currently being marketed by several manufacturers.

The advantages of size and weight of solid-state noise generators over gas-discharge types are obvious, but certainly not trivial. The typical unit for laboratory measurements is 4 to 6 inches long and weighs a few ounces. Most microwave UUTs are fitted with precision miniature connectors (SMA, etc.). The small size of the solid-state noise generator, as opposed to a gas-discharge unit weighing several pounds and requiring a waveguide to coaxial adapter, could be instrumental in preserving the integrity of the UUT input connector during testing.

Power requirements are another factor. Most laboratory sources operate on +28 volts at less than 15 ma. No ignition pulse is required (eliminating a potential EMI source) and temperature rise due to power dissipation is negligible.

The major advantage results from the high-level output of the noise diode. When this is padded down to a level compatible with most laboratory noise instruments (14 to 16 dB ENR), mismatch is improved significantly (depending, of course, on the quality of the source). As noted earlier, the output attenuator masks the mismatch change as the unit is switched from the cold to the hot condition. It is not unusual to find commercially available broadband units with "on" and "off" VSWR's less than 1.1:1 over large segments of their operating frequency range.

Solid-state noise generators can be turned on and off virtually as fast as the power source can be switched; thus, they are ideal for synchronous radar noise monitoring which requires the measurement be made during the radar dead time. Quite often, the time available is as small as 12 microseconds.

There is almost a bewildering variety of solid-state noise generators available from several manufacturers. Micronetics (Norwood, NJ), Microwave Semiconductor Corporation (Somerset, NJ), and Nore Microwave offer a wide array of broad and narrow band, coaxial and waveguide units operating up to 40 GHz with excess noise ratios ranging from 5 to over 40 dB.

The trend in units for laboratory applications, however, seems to be toward a smaller number of broadband units. Hewlett-Packard (Palo Alto, CA) offers only a single unit, their Model 346B (Figure 7), covering 10 MHz to 18 GHz.

Eaton Corporation, Electronic Instrumentation Division, takes the same approach with their 7618E, 10 MHz to 18 GHz, and the recently introduced 7626 (Figure 8) which covers 10 MHz to 26 GHz in a single coaxial unit. Eaton also manufactures narrow band, high level sources for systems applications.

Two factors need to be considered in the selection of a solid state noise generator: power supply compatibility and calibration accuracy. Most commercially avail-

Fig. 9 The Eaton 13611 Precision Test Receiver provides most of the elements required for accurate, manual Y-factor measurements.

able units for laboratory applications are designed to operate from +28 volts. This is consistent with the drive available from most noise figure instrumentation; however, many units manufactured for use with specific instruments or for special applications are designed to operate from other power sources. For example, noise generators provided with the Sanders Microwave Model 5440C Noise Figure Test Set are designed to operate from +22 volts.

Solid state noise generators are somewhat unpredictable, with regard to ENR versus frequency, in manufacture; consequently, each unit requires individual calibration. Most noise generator manufacturers use some form of radiometer which compares the noise output of the production unit to a noise standard traceable, where applicable, to the National Bureau of Standards.

Because NBS offers only partial frequency coverage at this time, Eaton Corporation noise standards are also traceable at some

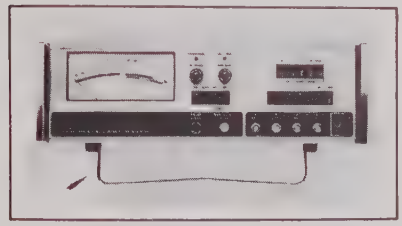


Fig. 10 ±0.05 dB tracking accuracy at low noise figures is featured by the Eaton 7514 Precision Automatic Noise Figure Indicator.

frequencies to the Electronic Quality Assurance Directorate (EQD), Aquila, Bromley, England.

It is important to note that most manufacturers of noise generators quote worst-case calibration uncertainty as an accuracy specification. At least one, however, also quotes a root-sum-squares uncertainty which gives the appearance of better accuracy.

Instrumentation

Early instrumentation used for noise figure measurements was a collection of the various elements required for a manual Y-factor measurement. Eventually, these were combined into a single instrument that included the precision attenuator, post-amplifier, detector, and analog indicator.

Instruments of this type are still available today (See Figure 9) because of their reliance on only measurable physical quantities for accuracy. These precision test receivers were usually designed to operate at a single frequency — typically, a popular intermediate frequency such as 30 MHz, for reasons of economy and attenuator accuracy. Therefore, mixer-preamplifiers operating from 10 MHz to 38 GHz, compatible with the measurement requirements, were added. Today, such receivers, in combination with thermal noise generators, can achieve noise figure instrumentation accuracies of ±0.1 dB.

The 1950s saw the emergence of the direct-reading, noise figure meter. Although inaccurate compared to today's instruments, these represented a major step forward in time-savings, since the measurement consisted of assembling the set-up and reading noise figure directly from a meter.

The early offerings by such as

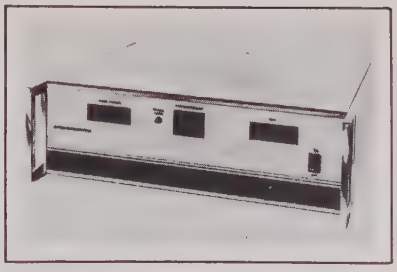


Fig. 11 The Eaton 7380 Noise/Gain Monitor is a bus-controllable instrument which can simultaneously measure the noise figure and gain of a unit under test.

AIL (later to become part of Eaton Corporation), Kay Electric, Hewlett-Packard, and Magnetics A.B. of Sweden featured accuracies ranging from ±0.5 to ±1 dB (exclusive of the noise generator).

All were essentially IF receivers, incorporating automatic gain control to insure the Y-factor signal remained in the linear range of the instrument. The noise-on and noise-off outputs of the UUT were separated by synchronous detection and the result was displayed

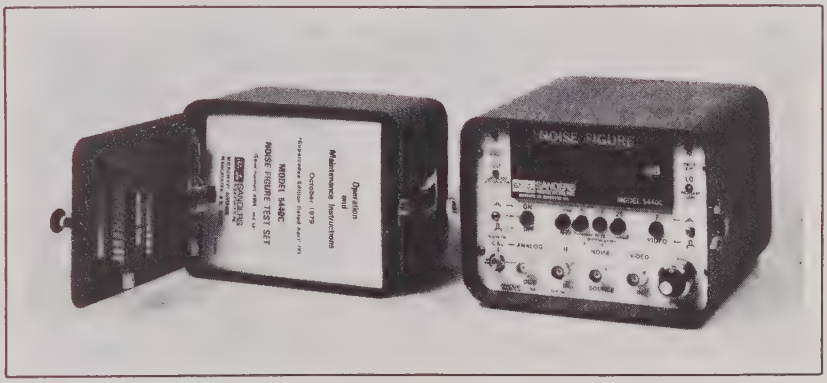


Fig. 12 The Sanders Model 5440C Noise Figure Test Set which can operate from the detected output of the UUT or with signals ranging from 10 MHz to 200 MHz. (Photo courtesy of Sanders Associates, Inc., Microwave Division).

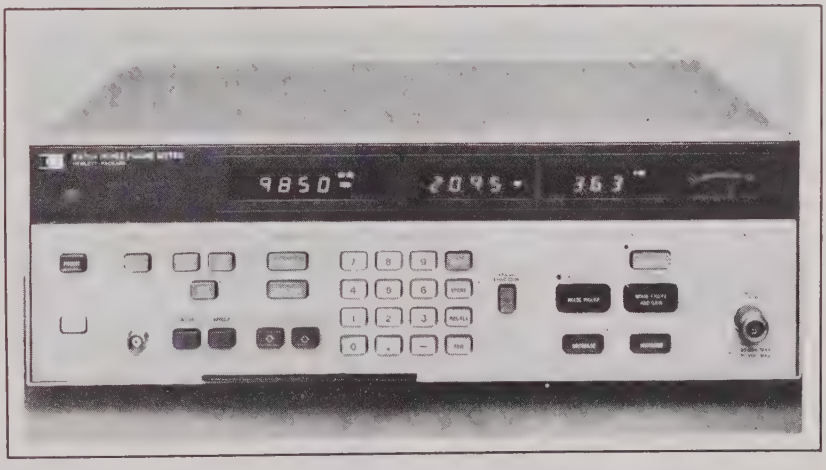


Fig. 13 The HP Model 8970A microprocessor controlled Noise Figure Meter featuring tunable 10 to 1500 MHz input, concurrent gain measurement and real-time second stage noise correction. (Photo courtesy of Hewlett-Packard.)

as noise figure, in dB, on a meter. All this was accomplished with analog circuitry.

A major accuracy breakthrough occurred in 1967 with the introduction of the AIL 75 Series. Instrument accuracy dropped to ±0.15 dB and a range of noise generator ENRs could be accommodated (earlier instruments were calibrated for, at most, two excess noise ratios).

The current model, the Eaton 7514 (Figure 10), features an instrument accuracy of ±0.05 dB in a laboratory environment. In conjunction with a precision calibrated noise generator, the measurement system is capable of a worst-case accuracy of ±0.2 dB (dependent upon RF frequency).

The 1970s saw the move toward digital circuitry, and in 1977 Eaton introduced the GPIB compatible 7370 and 7380 (Figure 11).

The Eaton 7300 Series System Noise Monitors were a move toward noise figure instrumentation tailored for specific test systems applications at reasonable cost. These instruments can be provided at several input frequencies, with either analog (meter) or digital readouts, with a variety of frequency, range and performance options, and in several mechanical configurations.

The Sanders Microwave 5400, introduced at about the same time, represented a solution to a specific problem. In many instances, it is difficult and inconvenient to extract a linear IF noise signal from the receiver under test. The current Sanders offering, Model 5440C (Figure 12), solves this problem by providing a video input which can operate off the detected output of the receiver. Thus, the need to probe or break into the IF circuitry of the receiver is eliminated. The Sanders 5440C also features a 10 MHz to 200 MHz preselected IF input and comes complete with noise generator, cables, adapters, etc. in a small carrying case.

The Eaton 7380, at its initial introduction in 1974, was rather unique. It was the first commercially available noise figure instrument that could simultaneously measure the gain of the UUT without breaking down the noise set up for CW signal insertion, power meters, or substitution attenuators. Subsequent addition of GPIB capability made this a powerful measurement tool for both laboratory and production tests of RF and microwave amplifiers. With a relatively simple program, a desk top computer, operating on the raw data output by the 7380, can provide virtually real-time display or hard-copy plots of both the noise figure and gain of the UUT. Using the power of the computer, the data can be corrected for such complicating factors as measurement system noise contribution (second-stage noise) and "cold" (noise generator off) temperature deviation from 290K.

One of the latest additions to the noise figure measurement field is the Hewlett-Packard 8970A (Figure 13). This instrument represents a significant departure from the design of other noise figure instruments in that it employs a resident microprocessor to calculate the selected noise parameter (noise figure or effective input noise temperature) from the raw Y-factor data. The microprocessor is also used to correct the results for second-stage noise and cold temperature deviations so that the stand-alone instrument provides, essentially, on-line corrected outputs. Like the Eaton 7380, the HP 8970A also provides a simultaneous readout of UUT gain.

The 8970A is representative of the general trend in instrumentation. Features such as tunability over a broad range (10 to 1500 MHz), on-line correction of the output data, storage of noise generator ENR versus frequency data, and selection of readout parameters are today's solutions to past measurement annoyances.

It is a virtual certainty that even more improvements in the measurement process will be forthcoming in the near future. Certainly, there is room for better accuracy, both in the measuring instrument and in particular, in the noise generator. The measurement process can be further eased for the operator, and his understanding of the results improved, by putting even more of the measurement burden on the instrumentation.

Summary

The instrumentation involved in noise figure measurements has improved dramatically over the past twenty years. The improvements are not only in accuracy but also in facilitation of the measurement procedure itself. Noise generators have progressed from cumbersome, fragile, high-voltage gas and thermionic devices to small, rugged, low-power solid-state units exhibiting comparable accuracies. The accuracies of the measuring instruments have shown even more improvement, and today's designs offer operator conveniences not even considered earlier. The future holds promise of even further improvements both in ease of performing the measurement and accuracy.

Acknowledgement

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REFERENCES

1. Mumford, W.W. and Scheibe, E.H., "Noise Performance Factors in Communications Systems," Artech House, Dedham, MA, 1968.
2. Miller, C.K.S., Daywitt, W.C., and Arthur M.G., "Noise Standards, Measurements, and Receiver Noise Definitions," Proc. IEEE, Vol. 55, No. 6, pp. 865-877, June 1967.
3. Wells, J.S., Daywitt, W.C., and Miller, C.K.S., "Measurement of the Effective Temperatures of Microwave Noise Sources," IEEE Trans. on Instr. and Meas., vol. IM-13, pp. 17-28, March 1964.
4. Mumford, W.W., "A Broadband Microwave Noise Source," Bell Sys. Tech. J., vol. 28, pp. 608-618, October 1949.
5. Miller, C.K.S., Daywitt, W.C., Campbell, E., "A Waveguide Noise Tube Mount for Use as an Interlaboratory Standard," Acta IMEKO III, pp. 371-381, 1964. ■

EATON Advanced Electronics

Transform Noise Figure To Noise Temperature

The noise figure of a low-noise amplifier can be converted into a value for the effective input noise temperature with several simple equations. The calculations also serve to check instrument uncertainties.

William E. Pastori, Director of Marketing, Eaton Corp., Electronic Instrumentation Div., 5340 Alla Rd., Los Angeles, CA 90066.

THE noise characteristics of most low-noise amplifiers are given by a manufacturer in terms of noise figure. One of the reasons is that the majority of available RF and microwave instrumentation is calibrated to measure this parameter in decibels. Occasionally, the need arises for an amplifier's noise characteristics in terms of the effective input noise temperature, a quantity measured in degrees Kelvin. The necessary calculations are straightforward.

Unfortunately, the evaluation of the uncertainty in the effective input noise temperature from the noise figure uncertainty (as derived from the related accuracy of the test equipment) is not always a simple task. Often an engineer will convert the noise figure uncertainty to a fractional uncertainty. Then, noting the simple linear relationship between the effective input noise temperature and the noise figure, when expressed as the ratio F, he will assume that the fractional uncertainty that applies to the noise figure measurement also applies directly to effective input noise temperature. The results can be misleading.

The calculations that follow avoid this misconception. For simplicity, all quantities given in decibels are marked with the prime symbol. For example, the noise figure uncertainty (in dB) can be expressed by the following equations:

$$\Delta F' = F'_H - F_0' \qquad (1)$$

$$\Delta F' = 10 \log_{10} \frac{F_H}{F_0} \qquad (2)$$

where F is the noise figure, F_0 is the nominal value of F, F_H is the upper limit of F, and ΔF is the uncertainty of F (and is equal to the difference between F_H and F_0).

The ratio of the upper limit of the noise figure to its nominal value can be given as:

$$\frac{F_H}{F_0} = 10^{\Delta F'/10} \qquad (3)$$

Bringing in the uncertainty quantity, ΔF, expressed as a ratio, we have

$$\frac{\Delta F}{F_0} = \frac{F_h - 1}{F_0} \qquad (4)$$

which, by combining with Eqs. 3 and 4, can be written as:

$$\frac{\Delta F}{F_0} = 10^{\Delta F'/10} - 1 \qquad (5)$$

This last equation relates the fractional uncertainty in the noise figure ratio $\Delta F/F_0$ to the decibel uncertainty.

The effective input noise temperature, T_E, is related to the noise figure by the expression:

$$T_E = (F - 1)\, 290 \qquad (6)$$

It should be mentioned that noise figure measurements sometimes include an image, such as the measurement of a broadband RF amplifier followed by a downconverter. Equation 6 is also valid if F is what is commonly referred to as the "double-sideband noise figure."

The uncertainty in T_E as a function of the noise figure uncertainty can be expressed as

$$\Delta T_E = \frac{\partial T_E}{\partial F} \Delta F \qquad (7)$$

By taking the derivative of this, a value for ΔT_E of 290F results. The simple matter of replacing ΔF with Eq. 5, and combining Eq. 6 with 290F gives:

$$\frac{\Delta T_E}{T_{E_0}} = \frac{(10^{\Delta F'/10} - 1)}{(1 - \frac{1}{F})} \qquad (8)$$

where T_{E_0} is the nominal value of T_E.

This last equation relates the fractional uncertainty in the effective input noise temperature to the decibel uncertainty in the noise figure. Due to the quantity in the denominator of Eq. 8, the T_E uncertainty is always larger than the fractional noise figure uncertainty. As an example, if an amplifier noise figure of 3 dB was measured with instrumentation having a ±0.3-dB uncertainty, the fractional uncertainty in the noise figure will be about ±7.2 percent. However, when using Eq. 8, the fractional uncertainty in the effective input noise temperature is found to be ±14.3 percent. This amounts to about ±41°K out of a T_E of 289°K. Written either way, the discrepancy is obvious and demonstrates the value of checking these noise uncertainties with Eq. 8. ••

Image and Second-Stage Corrections Resolve Noise Figure Measurement Confusion

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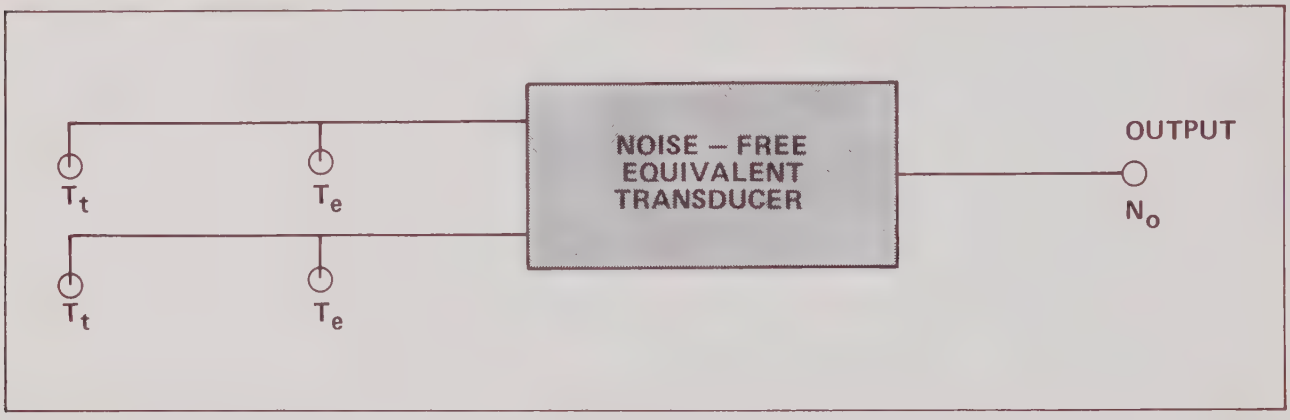
EATON

Image and Second-Stage Corrections Resolve Noise Figure Measurement Confusion

There is still considerable confusion over the effects of image response on a heterodyne measurement system, and corrections to be applied as a result of the noise performance of the measurement system itself.

By **William E. Pastori,** Eaton Corporation



1. Effective input noise temperature *is a term representing the internal noise generated by the transducer, exclusive of the source termination noise. This becomes clearer when viewed in terms of a noise equivalent diagram for a two-channel transducer which exhibits image and signal responses.*

The concept of noise figure has been in general use as a valuable measure of amplifier and receiver noise performance for many years; however, as evidenced by some past literature,[1] there is still considerable confusion over the effects of image response on a heterodyne measurement system, and corrections to be applied as a result of the noise performance of the measurement system itself. This situation is quite prevalent (and a continuing source of annoyance) among manufacturers and users of broadband microwave amplifiers.

We will attempt to resolve some of this confusion by analyzing a general measurement system and deriving 2nd stage/image corrections applicable to the two most common instrumentation configurations used to measure the noise figure of broadband, RF and microwave amplifiers.

Basic Considerations

Noise in amplifiers and receiving systems is characterized by the power available from a thermal noise source;[2, 3] that is,

$$P_n = kTB \qquad (1)$$

where P_n = noise power available
k = Boltzmann's Constant (1.28×10^{-23} joules/kelvin)
T = temperature of the source on the absolute scale (kelvins)
B = noise bandwidth (hertz)

Effective input noise temperature[4] can be described as the temperature of a fictitious thermal noise source which, if assigned *to all accessible input ports* of a noise-free equivalent of a noisy transducer (amplifier or receiver), would produce the same noise at the output as the actual transducer when terminated at the input by noiseless terminations. In effect, this term represents the internal noise generated by the transducer, exclusive of the source termination noise. This becomes clearer when viewed in terms of the noise equivalent diagram (Fig. 1) for a two-channel (heterodyne) transducer; that is, one which exhibits two responses (image and signal).

Note that, although a heterodyne transducer may have only a single, physical input port, it exhibits two electrical input ports—one representing the signal response and one representing the image response.

If the source termination temperatures at both input ports are equal (generally true for this type of system), the noise output of the transducer in Figure 1 can be written:

$$= kB\,(T_t + T_e)\,(G_i + G_s) \qquad (2)$$

where, T_t = source termination temperature (kelvins)
G_i = gain of the image channel
G_s = gain of the signal channel

Noise figure[5] can be described as the ratio of the total noise output of the actual transducer, when the noise temperature of the input termination is as the Standard Reference Temperature, to (290K), to that of an ideal, noiseless transducer of otherwise identical characteristics. The wording here is different from the IEEE definition, but the result is equivalent.

The key word is "ideal," since an ideal transducer would

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not be encumbered by a useless image channel that simply generates noise and does not amplify the signal—in effect, it degrades the output signal-to-noise ratio. The IEEE definition, as clarified later,[6] states that the denominator of the ratio "includes only that noise from the input termination which appears in the output via the principal-frequency transformation of the system . . . and does not include spurious contributions such as those from an unused image-frequency . . . ."

Thus, $$F = \frac{N_{Actual}}{N_{Ideal}} \quad (3)$$

In terms of effective input noise temperature,

$$F = \frac{kB(T_o + T_e)\ (G_s + G_i)}{kB\ T_o\ G_s} \quad (4)$$

and, $$F = \left(\frac{T_e}{T_o} + 1\right)\ \left(1 + \frac{G_i}{G_s}\right) \quad (5)$$

There are some important aspects of equations (2) through (5) that should be emphasized:

1. There is a noise term in the output of an ideal, noiseless transducer (T_e and $G_i = 0$) simply by virtue of the noise generated by the source termination.

2. The noise figure of the ideal, noiseless transducer is unity (0dB)—this is the minimum, theoretical noise figure.

3. The noise figure of a noiseless, heterodyne transducer ($T_e = 0$) is *not* unity, but is equal to:

$$1 + \frac{G_i}{G_s}$$

and, if one makes the general assumption that the image and signal channel gains are equal, this factor equals 2 (3dB)—the underlying reason why 3dB is generally added to the measured value of a mixer-preamplifier noise figure.

The noise figure described by equation (5) is usually referred to as "single sideband noise figure" since it accounts for the existence of an image response. The first parenthetical expression,

$$\frac{T_e}{T_o} + 1 \ ,$$

is generally referred to as "double sideband noise figure" when applied to heterodyne systems. As will be shown later, this is the only logical expression for the noise figure of a broadband RF or microwave amplifier, whose passband encompasses both image and signal responses of a following downconverter, since whether or not it should be corrected for image response depends upon the configuration of the receiver system to which it is applied.

Measurement Techniques

Receiver noise parameters are usually determined by measuring the ratio of the noise powers at the output of the device-undertest (DUT) for two known input noise conditions. The output ratio is referred to as the "Y-factor."

Figure 2 illustrates the method in simplified block diagram form. The noise generator provides the two known input noise conditions represented by source terminations with output noise temperatures T_H and T_C.

The output of the DUT is downconverted to an intermediate frequency (typically 30 MHz) so that the output ratio measurement can be performed at a single frequency. This optimizes accuracy, precision, and dynamic range of the measuring instrument at reasonable cost.

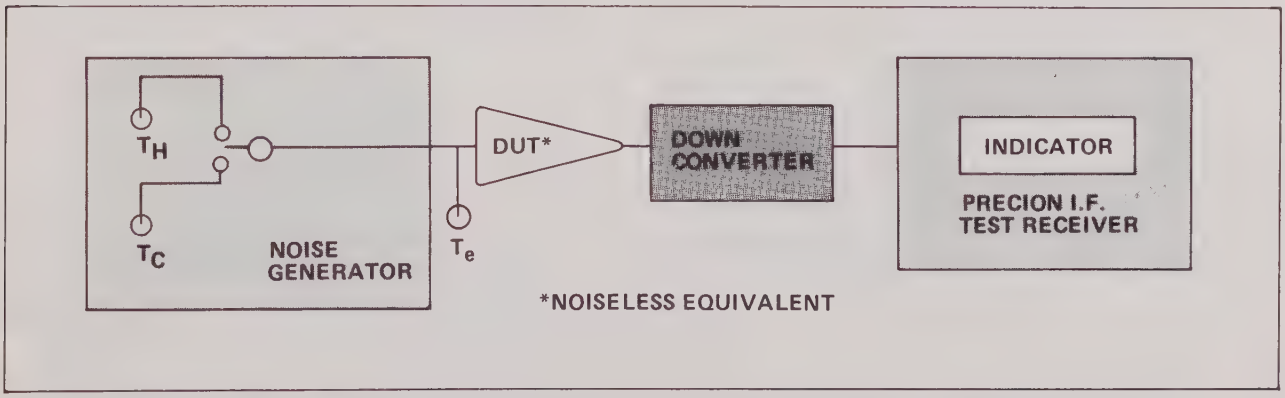
The Y-factor can be measured by manually substituting IF attenuation as the input termination is switched from the "cold" (T_C) to the "hot" (T_H) condition. The procedure is as follows:

1. With the source termination at T_C a reference indication is set on the Test Receiver.
2. The source termination is switched to T_H.
3. The attenuation at the input of the Test Receiver is increased until the indication returns to the reference.
4. The attenuation change (expressed as a ratio) is the Y-factor. The desired noise parameter (effective input noise temperature or noise figure) is calculated by means of Equations (7), (8), or (10).

Figure 3 is an example of a typical instrument used to implement the manual Y-factor measurement.

The manual IF attenuation substitution measurement is employed whenever accuracy is paramount; however, quite often, a slight accuracy degradation (typically 0.05 to 0.1 dB) is acceptable in view of the time and cost savings offered by direct reading instruments. These are basically IF receivers which automatically implement the Y-factor measurement, and calculate and display the result as noise figure. Figure 4 is an example of such an instrument.

The noise power applied to the test receiver or noise figure indicator is described generally by Equation (1).



***2. Receiver noise parameters** are usually determined by measuring the ratio of the noise powers at the output of the DUT for two known input noise conditions. The noise generator provides the two known input conditions represented by source terminations.*

Since the measured Y-factor is the ratio of two noise powers:

$$Y = \frac{kB\,(T_H + T_e)\,(G_s + G_i)}{kB\,(T_c + T_e)\,(G_s + G_i)} \qquad (6)$$

From this,

$$T_e = \frac{T_H - YT_c}{Y - 1} \qquad (7)$$

and,

$$F = \left[\frac{\frac{T_H}{T_o} - Y\frac{T_c}{T_o}}{Y - 1} + 1\right]\left[1 + \frac{G_i}{G_s}\right] \qquad (8)$$

Most commercial noise generators operate such that T_c equals room temperature, which is generally assumed equal to T_o (290K); therefore,

$$F = \left[\frac{\frac{T_H}{T_o} - 1}{Y - 1}\right]\left[1 + \frac{G_i}{G_s}\right] \qquad (9)$$

The quantity in the numerator of Equation (9) is a characteristic of the noise generator and is referred to as "Excess Noise Ratio" (ENR). Equation (9), *excluding* image considerations, is often expressed:

$$F_{dB} = ENR_{dB} - 10\,LOG_{10}\,(Y - 1) \qquad (10)$$

Virtually all direct-reading instruments indicate noise figure by implementing Equation (10) either by analog means (meter scale calibration), or digital computation.

It should be recognized, particularly with regard to Equation (10), that the measuring instrument has no way of separating the noise performance of the DUT from the contributions of subsequent elements of the measuring system (mixer-local oscillator, IF amplifiers, etc.); nor, can the instrument discern the existence or absence of an image response.

As a result, it may, depending upon the relative magnitudes of DUT gain and noise performance versus measuring system noise performance, be necessary to correct the measured result to account for "second-stage" noise and/or image noise contributions.

Practical Measurement Model

The approach used to evaluate potential corrections for image and second-stage noise is to set up a noise measurement model from which a general Y-factor equation can be derived. Known values can then be substituted for specific terms in the equation to account for a particular measurement system configuration (Fig. 5), and the corrections derived for that configuration.

The "interface network" is included so that the effects of a post-selection filter can be analyzed. It is assumed to be a lossy element with a transmission efficiency, n (a dimensionless ratio, less than unity, equal to the ratio of power output to power input). For simplicity, the network will be assumed to be at a noise temperature of 290K, T_o, the standard reference temperature. In a matched system, the effect of this network on noise is given by[7, 8]

$$T = nT_s + (1-n)\,T_o \qquad (11)$$

where, T = network output noise temperature
T_s = noise temperature (power) applied to the network input.

***3. A precision IF test receiver** is the typical instrument used to implement the manual Y-factor measurement. This substitution is employed whenever accuracy is of the greatest importance.*

Obviously, the term $(1-n)T_o$, represents the network's noise contribution to the output.

The analysis can be further simplified by also assuming:

- The cold temperature of the noise generator equals T_o.
- The image and signal channel gains of the mixer-IF amplifier are equal.

For further clarification of the terminology, subscripts are assigned in accordance with Figure 5, while superscripts are used to indicate either image or signal contributions, e.g.,

G_1^i = DUT gain at the image frequency

From these considerations, the noise power applied to the measuring instrument can be expressed:

$$No = kBG_2^s\left[T_{e_2} + (1-n^s)\,T_o + n^sG_1^s\,(T_t + T_{e_1})\right] + kBG_2^i\left[T_{e_2} + (1-n^i)\,T_o + n^iG_1^i\,(T_t + T_{e_1})\right] \qquad (12)$$

The measured Y-factor is simply the ratio of No when:

$$T_t - T_H$$

to that when:

$$T_t = T_o \text{ (for the indicated assumption).}$$

Therefore, with $G_2^s = G_2^i$,

$$Y = \frac{(T_H + T_{e_1})\,(n^sG_1^s + n^iG_1^i) + (2-n^s - n^i)\,T_o + 2T_{e_2}}{(T_o + T_{e_1})\,(n^sG_1^s + n^iG_1^i) + (2-n^s - n^i)\,T_o + 2T_{e_2}} \qquad (13)$$

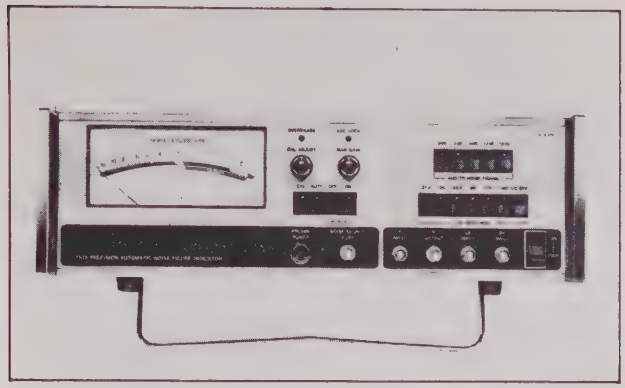
It is convenient at this point to form the expression,

$$Y-1 = \frac{(T_H - T_o)\,(n^sG_1^s + n^iG_1^i)}{(T_{e_1} + T_o)\,(n^sG_1^s + n^iG_1^i) + (2-n^s-n^i)T_o + 2T_{e_2}} \qquad (14)$$

$$= \frac{\left(\frac{T_H}{T_o} - 1\right)}{\left(\frac{T_{e_1}}{T_o} + 1\right) + \frac{2T_{e_2}}{T_o(n^sG_1^s + n^iG_1^i)} + \frac{2-n^s-n^i}{n^sG_1^s + n^iG_1^i}} \qquad (15)$$

The quantity, $\left(\frac{T_e}{T_o} + 1\right)$, is, as noted earlier, a "double

sideband" noise figure. For the remainder of this paper it will be assigned the symbol F_D; therefore,



4. Direct-reading instruments, *basically IF receivers which automatically implement the Y-factor measurement and calculate and display the result as noise figure, are not as accurate as precision IF test receivers used for manual measurements. However, the slight, 0.05 to 0.1 dB, degradation is acceptable in view of time and cost savings.*

$$F_{D_1} = \left(\frac{T_{e_1}}{T_o} + 1\right) \tag{16}$$

and,

$$2\frac{T_{e_2}}{T_o} = 2\,(F_{D_2} - 1) \tag{17}$$

Also,
$$\left(\frac{T_H}{T_o} - 1\right) = ENR \tag{18}$$

Therefore, Y-1 $=$
$$\frac{ENR}{\left(F_{D_1} + \dfrac{2\,(F_{D_2} - 1) + 2 - n^s - n^i}{n^s G_1^s + n^i G_1^i}\right)} \tag{19}$$

As described earlier, noise figure is calculated—either manually or by the instrumentation—by means of Equation (10), repeated here for reference (expressed in ratio form rather than in dB).

$$F_C = \frac{ENR}{Y - 1} \tag{20}$$

Thus,
$$F_C = F_{D_1} + \frac{2(F_{D_2} - 1) + 2 - n^s n^i}{n^s G_1^s + n^i G_1^i} \tag{21}$$

Since the point of this exercise is determination of DUT noise performance, (21) can be re-written:

$$F_{D_1} = F_C - \frac{2(F_{D_2} - 1) + 2 - n^s n^i}{n^s G_1^s + n^i G_1^i} \tag{22}$$

F_{D_2} is the double sideband noise figure of the mixer and subsequent elements of the measurement system since it was assumed that the mixer-IF amplifier has equal conversion gains at both signal and image frequencies.

The fractional second term is the contribution of the measuring system following the DUT. The implication here is that F_{D_1} and G_2 refer to all elements, including the instrumentation, following the inserted network, n.

The following sections will show how Equation (22) can be used to evaluate the second stage and image contributions of two specific measurement configurations.

Broadband Amplifier—No Filter

One of the most prevalent situations encountered in practice is when the DUT has sufficient bandwidth to encompass both the image and signal frequencies of the downconverter, and its output is directly connected in a lossless manner, to the mixer input. In terms of Figure 5,

$$n^s = n^i = 1 \cdot$$

Applying these conditions to Equation (22),

$$F_{D_1} = F_C - \frac{2(F_{D_2} - 1)}{G_1^s + G_1^i} \tag{23}$$

It should be immediately recognized that (except for the designation of F_{D_1} and F_{D_2} as double sideband noise figures) if, $G_1^s = G_1^i$ the form of Equation (23) is identical to the classic Friis relation[9] for second stage noise contribution of a single response system

Another interesting aspect illustrated by Equation (23) is that because the mixer-amplifier exhibits two responses, its *contribution,* the quantity $(F_{D_2} - 1)$, is doubled. Many individuals will double the noise figure (add 3dB); converting it to single sideband, and then attempt to evaluate the effect. This is an unnecessary, needless complication, since (23) is already in a form incorporating directly measurable quantitites.

Broadband Amplifier Followed By An Image—Reject Filter

In some instances, attempts will be made to "simplify" the measurement setup by inserting a filter between the output of the DUT and the mixer input to eliminate the DUT image response. If the filter is ideal, then:

$$n^s = 1$$

$$n^i = 0$$

and,
$$F_{D_1} = F_C - \frac{2(F_{D_2} - 1) + 1}{G_1^s} \tag{24}$$

The numerator of the second term could have been combined and simplified; however, in the present form it again illustrates that the noise contribution (not the noise figure) of the mixer-amplifier is doubled to account for the existence of an image response. The additional term in the numerator (+1) represents the noise contribution of the filter as a source termination for the mixer at the image frequency.

In instances where the frequency separation between the responses is small in comparison to the measurement frequency (essentially, the local oscillator frequency), this configuration offers no real advantages over the preceding set-up. The measurement result is essentially the same for a high gain DUT, and the magnitude of the correction is larger for a low gain DUT.

In practice, the filter will never be "ideal." There will be some loss at the signal frequency, and the loss at the image frequency will be finite; i.e.,

$$n^s < 1$$

$$n^i > 0$$

If these terms are significant, it may be necessary to apply

the more complex Equation (22) to ascertain the correction.

Another filter characteristic of importance is that it must present a good match to the mixer at both image and signal frequencies. This condition is not always achieved in practice. If the mixer-amplifier noise figure (F_{D2}) is measured under well matched conditions (as it should be), the noise figure could change when inserted in a system presenting a poor source match.

One further consideration, primarily affecting automated or swept measurement systems is the requirement that the filter center frequency track the local oscillator frequency, offset by the IF to a high degree of precision to insure repeatable results. At microwave frequencies the filter is often a YIG device, raising questions of tracking accuracy and hysteresis.

Receiver noise parameters are usually determined by measuring the ratio of the noise powers at the output of the DUT for two known input noise conditions.

These disadvantages generally outweigh any sense of security gained by insuring a closer approximation to spot noise figure measurements; however, below a few hundred megahertz, the percentage of the center frequency represented by the separation of the individual responses, and the variation with frequency of the quantities making up the Y-factor equation, may dictate the need for an image reject (or signal pass) filter.

In these cases, consideration should be given to the potential pitfalls noted above.

Application To Receivers

The question that generally arises is what relation does the noise figure derived above have to the DUT's "true" noise figure when the device is made part of a receiver system, and how is it related to overall receiver noise performance?

Low noise, broadband amplifiers are designed into the front-ends of receiver systems as a means of improving the overall noise performance of the receiver. The typical receiver configurations are virtually identical to the measurement set-up illustrated by Figure 5 (the noise generator would be replaced by the actual source termination). The most common arrangement includes the image-reject (or signal-pass) filter since, as will be shown, it provides the greatest improvement in terms of noise performance.

The overall receiver noise figure can be evaluated by assuming the source termination is 290K (T_o, the standard reference temperature) and applying Equation (3), to the definition of noise figure. Thus, for the general configuration:

$$F = \frac{N_{ACT}}{N_{IDEAL}} = \Big[G_2^s \big[T_{e_2} + (1-n^s)T_o + n^s G_1^s (T_{e_1} + T_o) \big] + G_2^i \big[T_{e_2} + (1-n^i)T_o + n^i G_1^i (T_{e_1} + T_o) \big] \Big] \Big/ G_2^s n^s G_1^s T_o \qquad (25)$$

As a means of checking Equation (25), let:

$$G_2^i = 0$$
$$n^s = n^i = 1$$

This corresponds to a single-response receiver with no intermediate elements between the first and second stage (the same conditions cna be applied to a receiver with a perfect, image-reject mixer/IF amplifier). Then (eliminating superfluous superscripts),

$$F = \left(\frac{T_{e_1}}{T_o} + 1 \right) + \frac{T_{e_2}}{G_1 T_o} \qquad (26)$$

and,

$$F = F_1 + \frac{F_2 - 1}{G_1} \qquad (27)$$

(27) is immediately recognizable as the standard, cascade-element noise figure relation normally applied to single response systems.

Again, assuming $G_2^i = G_2^s$ Equation (25) can be rearranged as follows:

$$F = \left(\frac{T_{e_1}}{T_o} + 1 \right) \left(1 + \frac{n^i G_1^i}{n^s G_1^s} \right) + \frac{2\left(\frac{T_{e_2}}{T_o} + 1 \right) - (n^i + n^s)}{n^s G_1^s} \qquad (28)$$

and, as defined earlier,

$$\left(\frac{T_{e_1}}{T_o} + 1 \right) = F_{D_1} \qquad (29)$$

$$\left(\frac{T_{e_2}}{T_o} + 1 \right) = F_{D_2} \qquad (30)$$

The solution for both most common configurations can be written almost by inspection.

When the receiver is comprised of a broadband amplifier followed by an image reject filter and a double sideband downconverter:

$$n^s = 1$$
$$n^i = 0$$

and,

$$F = F_{D_1} + \frac{2(F_{D_2} - 1) + 1}{G_1^s} \qquad (31)$$

If the filter is eliminated; i.e.,

$$n^s = n^i$$

$$F = F_{D_1} \frac{(1 + G_1^i)}{G_1^s} + \frac{2(F_{D_1} - 1)}{G_1^s} \qquad (32)$$

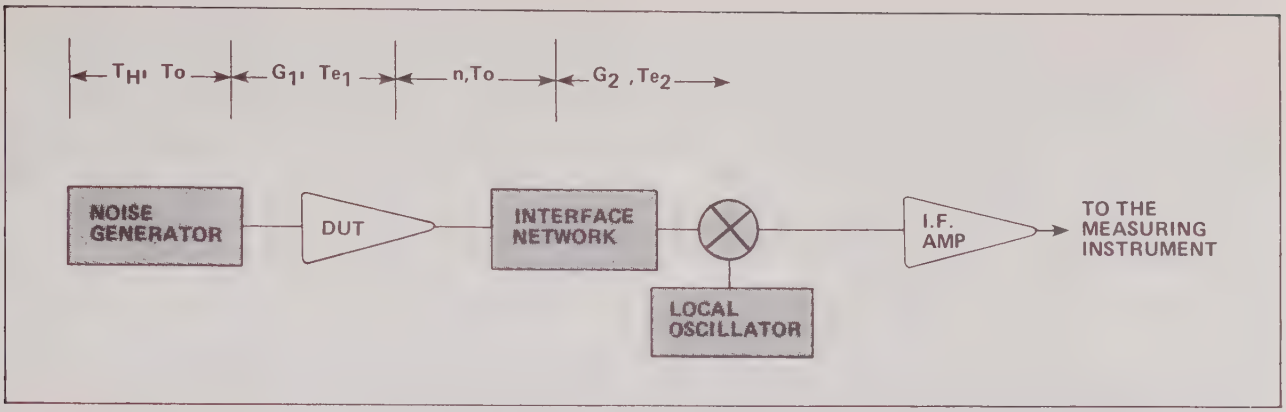
It can be seen from (31) and (32) that whether or not the so-called "double sideband" noise figure of the amplifier is corrected for image response depends entirely upon the configuration of the receiver in which it is used. As mentioned earlier, it then seems illogical to express the noise figure of a broadband amplifier in any way other than double sideband.

Reducing The Correction Magnitude

Quite often, particularly when dealing with microwave amplifiers, the gain of the DUT is relatively low, and the correction to be applied to the measured result is large in comparison to the DUT noise figure. As an example, assume a measurement made without a post selection filter, ((23) is the measurement equation) and the following conditions:

$$F_{D_1} = 1.585\ (2\text{dB})$$
$$F_{D_2} = 3.981\ (6\text{dB})$$
$$G_1^i = G_1^s = 6.310\ (8\text{dB})$$

Applying (23), it can be seen that the noise figure indicated by a direct reading instrument, or calculated from a manual Y-factor measurement would be about 3.13dB—a



5. In the practical measurement model, *the approach used to evaluate potential corrections for image and second-stage noise is to set up a noise measurement model from which a general Y-factor equation can be derived. The interface network is included so that the effects of a post-selection filter can be analyzed.*

significant departure from the desired DUT noise figure.

Both (23) and (24) indicate means of reducing the correction magnitude and, in many instances, rendering it negligible; i.e., reduce the noise of the second-stage and/or increase the amount of low noise gain ahead of the noisy downconverter. Consider a measurement system (Fig. 6) in which an RF amplifier identical to the DUT is inserted just ahead of the downconverter. Applying the general Y-factor equation (adding subscripts as necessary):

$$Y\text{-}1 = \frac{ENR}{F_{D_1} + \dfrac{(F_{D_2}-1)}{(G_1^s G_2^s + G_1^i G_2^i) \,/\, (G_2^s + G_2^i)}} + \frac{\dfrac{ENR}{2(F_{D_3}-1)}}{(G_1^s G_2^s + G_1^i G_2^i)} \qquad (33)$$

and,

$$F_C = F_{D_1} + \frac{(F_{D_2}-1)}{(G_1^s G_2^s + G_1^i G_2^i) \,/\, (G_2^s + G_2^i)} + \frac{2(F_{D_3}-1)}{(G_1^s G_2^s + G_1^i G_2^i)} \qquad (34)$$

Note, that if, $G_2^s = G_2^i$, (35) could almost be written by inspection:

$$F_C = F_{D_1} + \frac{2(F_{D_2}-1)}{G_1^s + G_1^i} + \frac{2(F_{D_3}-1)}{G_2(G_1^s + G_1^i)} \qquad (35)$$

which is recognizable as a simple extension of (23).

Using the same numerical values as in the earlier example:

$F_{D_1} = 1.585$ (2dB)
$F_{D_2} = 1.585$ (2dB)
$F_{D_3} = 3.981$ (6dB)
$G_1^s = G_2^i = G_2^s = G_2^i = 6.310$ (8dB)
$F_C = 1.91$ (2.81dB)

As can be seen, the correction is considerably smaller.

Equation (35) can be simplified to estimate the required correction by assuming:

$$G_1^s = G_1^i$$

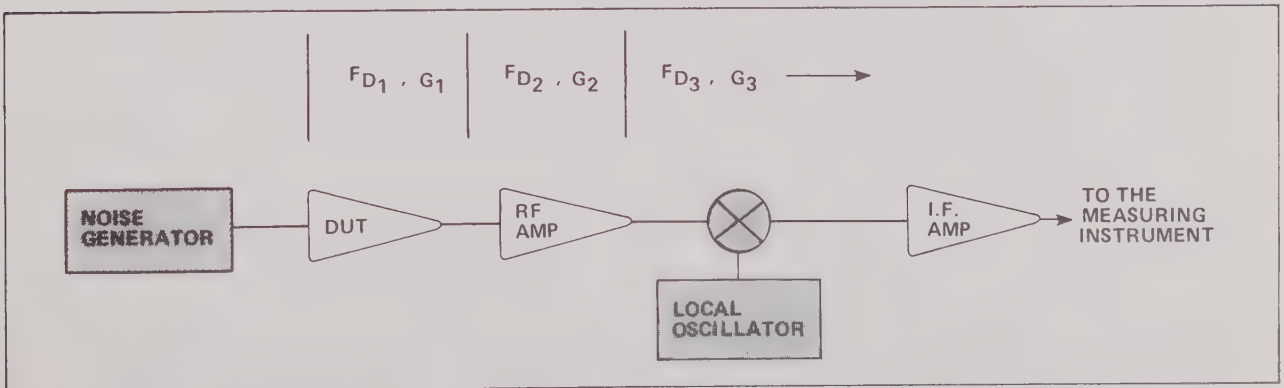
and,

$$G_2^s = G_2^i$$

Then,

$$F_C = F_{D_1} + \frac{F_{D_2}-1}{G_1} + \frac{F_{D_3}-1}{G_1 G_2} \qquad (36)$$

The process of cascading low noise amplifiers could, theoretically, be carried on indefinitely; however, there will be a "point of diminishing returns." An additional danger



6. The noise figure *indicated by a direct reading instrument would be about 3.1 dB, a significant departure from the desired DUT noise figure. In such a case, a measurement system such as this one, in which an RF amplifier identical to the DUT is inserted ahead of the downconverter, provides better results.*

is the possibility that if too much gain is inserted, some element further down the measurement chain will be overdriven, or the entire set-up could break into oscillation.

There seems to be a widespread misunderstanding of the effects of an image response on both the measured value of noise figure and application of the measured value to an actual receiver configuration.

The confusion can be dispelled by logical extension of basic definitions to specific measurement and receiver configurations as derived from more general configurations. A good deal of the misunderstandings between manufacturers and users of broadband amplifiers can be resolved by standardization on "double sideband noise figure" as a specification.

At microwave frequencies the filter is often a YIG device, raising questions of tracking accuracy and hysteresis.

Corrections to measured values of noise figure to arrive at a value more indicative of the actual noise figure of the DUT can be reduced by preceeding the downconverter with one or more low noise amplifiers.

However, it should be kept in mind that there is a danger in the simplistic application of the classic 2nd stage noise figure equation to measurement systems used to evaluate broadband amplifiers. ■

References

1. J.B. Winderman, "Perform True DSB to SSB Noise Figure Conversions," *Microwaves*, July 1980
2. H. Nyquist, "Thermal Agitation of Electric Charge in Conductors," *Physical Review*, Vol. 32, July 1928, p. 110
3. J.B. Johnson, "Thermal Agitation of Electricity in Conductors," *Physical Review*, Vol. 32, July 1928, p. 97.
4. "IRE Standards on Electron Tubes: Definition of Terms, 1962 (62 IRE 7.52)," *Proc. IEEE*, Vol. 51, March 1963, pp. 434 435.
5. "IRE Standards on Electron Tubes: Definition of Terms, 1957, (57 IRE 7.52)," *Proc. IRE*, Vol. 45, July 1957, pp. 983 1010.
6. IRE Subcommittee 7.9 on Noise, "Description of the Noise Performance of Amplifiers and Receiving Systems," *Proc. IEEE*, Vol. 51, March 1963, pp. 436 442.
7. A. Van der Ziel, "Noise", New York: Prentice Hall, 1954.
8. J.E. Sees, "Fundamentals in Noise Source Calibrations at Microwave Frequencies," U.S. Naval Research Lab., Rept. 5051, January 1958.
9. H.T. Friis, "Noise Figure of Radio Receivers," *Proc. IRE*, Vol. 32, No. 7, July 1944, pp. 419 422

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Noise-gain analyzer sets measurement accuracy standard

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E·A·T·N

Noise-gain analyzer sets measurement accuracy standard

With an accuracy within ±0.05 dB, the model 2075 noise-gain analyzer has emerged as a new reference in automated noise-figure instrumentation. In addition, two microprocessors make the analyzer easy to use.

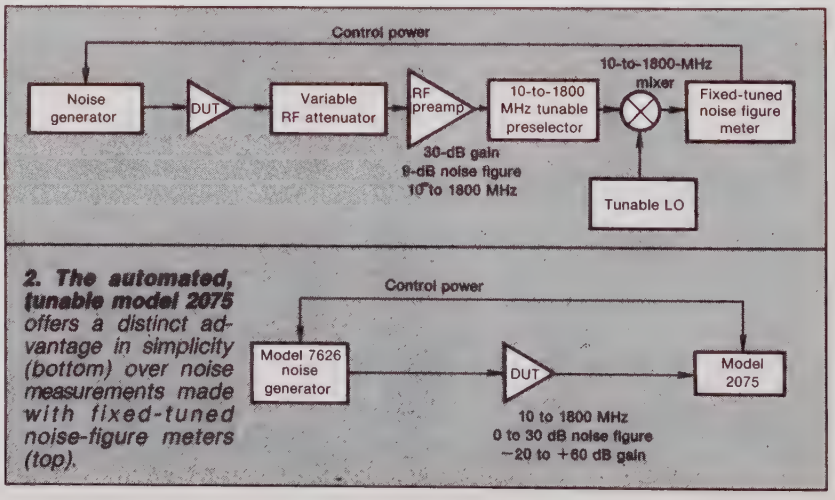
R.W. Green, Manager, UK Office, and **William E. Pastori,** Director of Marketing, Eaton Corp., Electronic Instrumentation Div., 5340 Alla Rd., Los Angeles, CA 90066

It has been 30 years since Eaton's AIL Div. introduced their first automatic noise-figure meter, the type 72. In the ensuing time, a complete range of specialized noise measurement equipment has been developed to serve a variety of noise-related applications. And now, with the introduction of the model 2075 noise-gain analyzer, those 30 years of engineering tradition have brought about a new standard of accuracy in noise-figure instrumentation.

The model 2075 has several outstanding features. For one, it is broadband, with a tunable frequency range of 10 to 1800 MHz (with 1-MHz resolution). Compared to techniques involving fixed-tuned noise-figure meters, this frequency range permits measurements to be made in a much simpler manner. Secondly, it has a gain measurement range of −20 to +65 dB and is sensitive enough to calculate its own noise figure. Last but not least, the instrument shows some very good numbers for measurement accuracy and resolution, at ±0.05 (for noise figures from 0 to 12 dB) and 0.01 dB, respectively.

Accuracy has long been a key issue in the noise measurement field. In order for a noise-analysis instrument to maintain a high degree of accuracy, it *must* have sufficient gain to make a reading of its own noise figure (second-stage noise corrections). The 2075 accomplishes this with its broad gain-measurement range, which is coupled with an accuracy of no worse than ±0.1 dB for noise figures higher than 12 dB. All readings are displayed with a resolution of 0.01 dB. Because of its own high gain, the model 2075 can operate from 10 to 1800 MHz without external preamplifiers, mixers, and local oscillators (LOs). For basic measurements, the only additional equipment needed is a noise generator.

1. The model 2075 noise-gain analyzer *brings a frequency range of 10 to 1800 MHz and a measurement accuracy of within ±0.05 percent to noise-figure measurements.*



2. The automated, tunable model 2075 *offers a distinct advantage in simplicity (bottom) over noise measurements made with fixed-tuned noise-figure meters (top).*

The model 2075 is basically a very accurate receiver. It has been designed with virtually the same double upconversion technique used in the firm's spectrum analyzers (Fig. 3). In those analyzers, the technique allowed frequency coverage from very low frequencies to above 1800 MHz by using a fundamental-frequency YIG oscillator as the source of upconversion LO frequencies. In the model 2075, a similar design was employed, except that a higher-frequency, 2.2-to-4.0-GHz YIG oscillator serves as the LO. The design technique gives the noise-gain analyzer swept input capability across its entire RF range.

The 2075 will sweep across frequencies in increments as small as 1 MHz. And for narrowband measurements at sweep widths of 10 MHz or less, the instrument can be swept in 100-kHz increments. The fixed or swept tuning of the analyzer is accomplished via microprocessor control of the YIG tuning oscillator. To keep the YIG on frequency, frequency correction is applied automatically at predetermined time intervals.

Wideband input amplifier

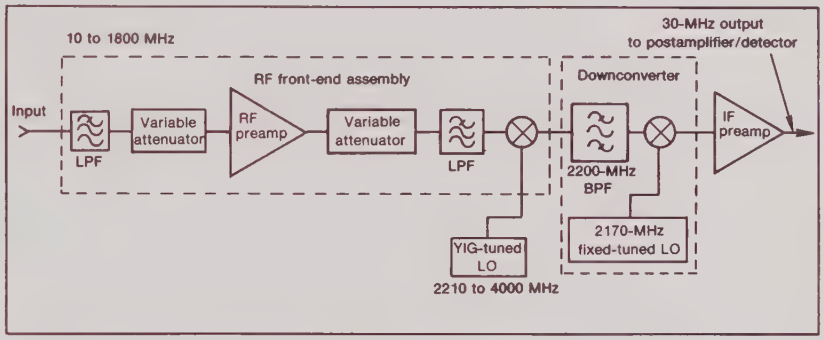
The front end of the 2075 consists of a wideband input amplifier with a noise figure of better than 9 dB across the 10-to-1800-MHz band. With the boost from this stage (and, thus, the added sensitivity), the 2075 can perform noise-figure measurements on negative-gain devices (such as mixers and attenuators) that have effective insertion losses as high as 20 dB. In the 2075's front end, the input amplifiers, low-pass filters, and the upconversion mixer are constructed in microstrip.

Once the input signal has been upconverted, it is applied to a 2200-MHz, three-pole bandpass filter to suppress excess image responses. This filter and the fixed-frequency, second LO have been designed as a single assembly in order to ensure both reliability and maximum frequency stability with changing temperature.

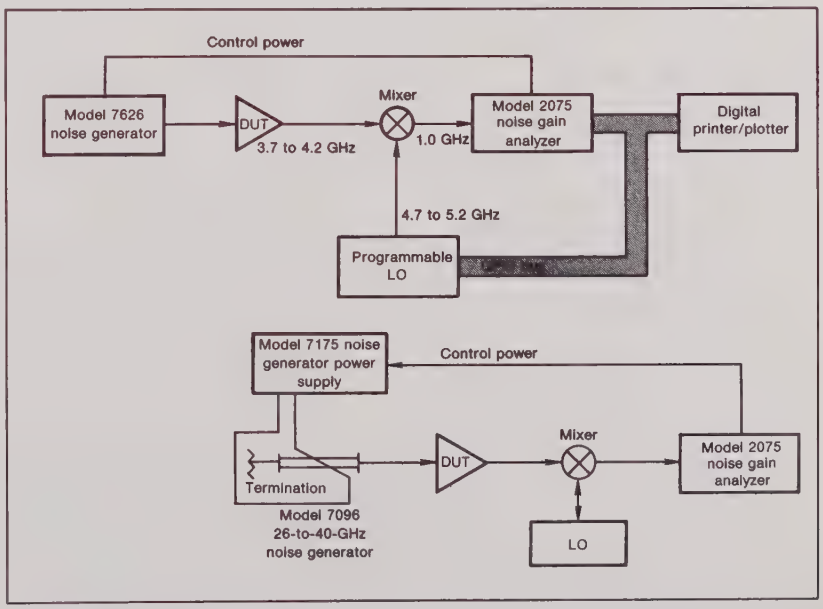
A single downconversion system was employed for minimum complexity and high reliability. A 30-MHz intermediate frequency (IF) was chosen as the optimum point for the gain/bandwidth requirements of the measurement system. The total IF gain can be controlled from 65 to 110 dB. It was important to maintain amplifier and detector linearity for the accurate measurement of low-level signals. The result is the measurement accuracy mentioned previously. (For a quick glance at the key specifications, see the table on the unit's key specifications, see the table above.)

A quick look at the model 2075 noise-gain analyzer

Parameter	Specification
Noise figure range	0 to 30 dB
Measurement accuracy	±0.05 dB (at NF = 0 to 12 dB) ±0.1 dB (at NF > 12 dB)
Measurement resolution	0.01 dB
Gain range	−20 to +65 dB
Measurement accuracy	±0.2 dB
Resolution	0.01 dB
Frequency range	10 to 1800 MHz
Tuning accuracy	± [0.5 MHz + 0.005f) (f in MHz)]
Frequency resolution	1 MHz
Input SWR	< 1.5:1
Measurement speed	6 to 10 measurements/s
Noise source drive levels	+28 ± 0.05 VDC
Operating temperatures	0 to 55°C
Storage temperatures	−55 to +75°C



3. The dual-conversion frequency processing *of the model 2075 takes inputs from 10 to 1800 MHz and turns them into 30-MHz outputs to be analyzed with the aid of an arithmetic microprocessor.*



4. These two test setups *show how the model 2075 can be used to make noise measurements at 3.7 to 4.2 GHz (bottom) and 26 to 40 GHz (top).*

Two microprocessors are built into the 2075. All control functions are managed by a 68000 series device (Motorola) while a separate arithmetic unit is used to perform data manipulation and "number crunching." By relying on two microprocessors instead of the customary single device, and on a fast analog-to-digital converter to handle the output of the detector, it was possible to achieve a relatively fast data reading rate. The 2075 can make measurements at speeds up to 100 ms/measurement.

It is a simple matter to enter effective noise ratio data with the 2075. A front-panel key permits entry of up to 31 noise-source calibration data points. A total of four sets of tables can be stored so that the correct set may be recalled when more than one source is used.

The front panel clearly displays numerical values for frequency, gain, and noise. Since gain and noise figures are interactive characteristics, it is especially important to have a simultaneous display of the two parameters. Noise figures and Y factors can be measured as a ratio, read out in decibels, or presented in degrees Kelvin as the effective input-noise temperature. Both gain and noise figure are simultaneously indicated on analog meters below the digital displays, a handy feature when gain and noise figure must be optimized. In addition to the instrument's self-contained readouts, gain and noise measurements can be displayed on an oscilloscope or X-Y plotter. Front-panel keys provide adjustment of the output drive levels so plots can be calibrated within lower and upper limits for maximum recording accuracy.

Up to nine separate front-panel settings can be stored in memory and later recalled, as they might be needed for operation by new or unskilled technicians. In addition, the last front-panel configuration prior to a CLEAR command is automatically stored in memory and can be recalled simply by hitting the RECALL button.

In order to simplify calibration in production and systems applications, relay power is available from the front panel. Coaxial relays can be used to bypass the device under test, enabling the noise source to be connected directly to the instrument for automatic gain and noise calibration.

Reaching high ranges

Very little additional equipment is needed with the 2075 for noise measurements above 1800 MHz. Two sample setups for higher-frequency work are shown in Fig.4. Both take advantage of the 2075's ability to control GPIB-compatible associated instrumentation. Broadband noise sources such as the model 7626 (see *Microwaves & RF*, June 1983, p. 114 for a review) make it possible to perform measurements all the way up to 26 GHz. The noise-gain analyzer sends a drive level of +28 VDC to turn on the noise source; this level decreases to less than +1 VDC to turn off the noise source. Prior to measurements, an operator need only enter the ambient temperature of the test room into the 2075's memory. The instrument then makes the necessary compensation for deviations from the reference noise temperature of 290° K.

At frequencies higher than 26 GHz, most noise parameter measurements must be implemented with gas-discharge noise generators. These require a special power supply to provide the high-voltage (1 to 5 kV at about 200 mA) ignition pulse needed to ionize the gas. Such a setup is also shown in Fig. 4, with a model 7175 triggerable power supply pushing a model 7096 noise generator. The power supply is run from the +28-VDC output from the 2075.

The noise-gain analyzer accepts input levels of up to +25 dBm without damage. It can operate from 0 to +55°C, can be stored at temperatures from −55 to +75°C, weighs 34 lbs., and measures 5.75 × 16.875 × 14 in. P&A: $10,000 to $12,000; 12 wks. **Eaton Corp., Electronic Instrumentation Div., 5340 Alla Rd., Los Angeles, CA 90066. (213) 822-3061, TWX: (910) 343-6969.**

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- The AILTECH 2075 Noise-Gain Analyzer
- The Impact of Microprocessor Technology on Receiver/Amplifier Noise Measurements
- High Accuracy Noise Figure Measurements
- Practical Considerations in the Measurement of Transducer Noise Performance

THE AILTECH 2075 NOISE GAIN ANALYZER

PRESENTED AT THE 22ND CONVENTION OF
THE AUTOMATED RF TECHNIQUES GROUP

NOVEMBER 3, 4, 1983
ALBUQUERQUE, NEW MEXICO

BY

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DIRECTOR OF MARKETING

EATON CORPORATION
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I. INTRODUCTION

The AILTECH 2075 Noise Gain Analyzer represents the latest effort of the Electronic Instrumentation Division (EID) of EATON Corporation in the field of receiver/amplifier noise parameter measurements. As most of you know, EID is the successor organization to that segment of the original Airborne Instruments Laboratory (AIL) that has pioneered direct reading noise figure instrumentation since the late 1940's.

The basic purpose of the instrument is measurement of the noise figure of amplifiers and receivers operating at RF and microwave frequencies; however, because of its radical departure from our earlier designs, the 2075 is capable of providing the user with much more information about the unit under test (UUT), in a more useable form with virtually on-line correction of several factors affecting the accuracy and validity of the measurement.

These features come about through an almost perfect marriage of currently available technology and the characteristics of the measured parameter. Noise figure and its associated parameters are calculated entities derived mathematically from a voltage or power ratio measurement similar in concept to reflection coefficient or return loss. The measurement requirement then, provides an ideal environment for a resident microprocessor application.

Once the local calculation power is in place, the instrument is no longer limited to readout of a single parameter. Upon operator demand, readout can be in terms of other receiver noise parameters such as effective input noise temperature or operating noise temperature. In addition, since it is related to the same ratio measurement, gain of the UUT can also be derived.

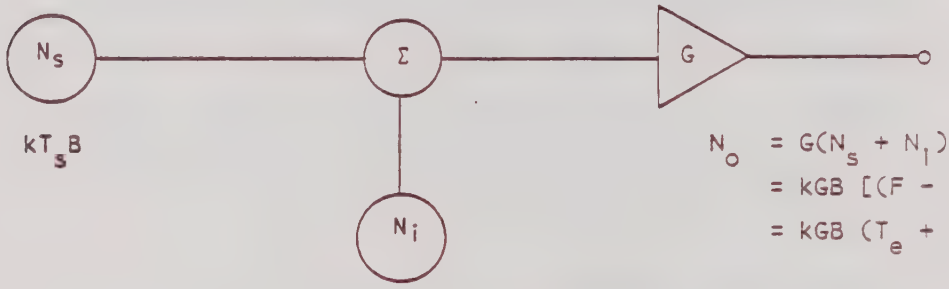
The most important aspect, however, is that with local computing capability, and given the appropriate inputs, the instrument can correct the results for such factors as second-stage noise, excess noise ratio variability and cold temperature deviation from 290 K (the standard reference temperature).

Placing the burden of these repetitive, corrective calculations on the machine relieves the user of hours of off-line secondary measurements and

calculation, and under computer control, eliminates a good deal of the software effort.

II. SOME BASIC CONSIDERATIONS

The concept of noise figure is illustrated by the basic noise model shown below:



Noise figure can be defined as the ratio of the actual noise power output of the transducer to that of an ideal noiseless transducer of otherwise identical characteristics when the source termination is at the standard reference temperature, 290 K (T_o).

$$F = \frac{N_o}{N_{ideal}} = \frac{N_o}{kT_oB} \qquad (1)$$

Noise figure is generally determined by measuring the ratio or change in the transducer output noise power as the source temperature is switched between two known temperatures. This ratio is commonly referred to as Y-factor.

$$Y = \frac{N_{o_H}}{N_{o_C}} = \frac{(F - 1)T_o + T_H}{(F - 1)T_o + T_C} \qquad (2)$$

$$F = \frac{\left(\frac{T_H}{T_o} - 1\right) - Y\left(\frac{T_C}{T_o} - 1\right)}{Y - 1} \qquad (3)$$

The first quantity in the numerator of the preceding equation is known as excess noise ratio; that is,

$$ENR = \left(\frac{T_H}{T_o} - 1\right) \qquad (4)$$

It is a measure of the noise power output of the noise generator.

If the cold temperature of the noise generator equals the standard reference temperature, T_o (a generally invalid assumption), then:

$$F = \frac{ENR}{Y - 1} \qquad (5)$$

$$F_{dB} = ENR_{dB} - 10LOG_{10}(Y - 1) \qquad (6)$$

Due to time and length constraints, no analysis is made here of the complications arising from multiple responses (such as in a heterodyne system) in either the UUT or the measuring systems; however, it should be recognized that the existence of such responses can have a significant effect on the measurement.

III. SOME COMPLICATIONS

Termination Temperature Error

An obvious source of correctable error is illustrated by the foregoing equations: earlier instrumentation calculated noise figure using the

simplified equation based on the source termination temperature being equal to the standard reference temperature. As noted, the assumption is usually invalid (290 kelvins is about 62°F).

The error is not significant in most measurements made in a laboratory environment except in the measurement of very low noise devices (<2 dB).

Image Response

The existence of an image response in either the UUT or the measuring system may require adjustment of the measured result. In mixer measurements, it is common practice to add 3 dB to the measured value using the assumption that the conversion losses at the image and signal frequencies are equal.

Indicator Input Frequency

For reasons of accuracy and economy, earlier noise figure instrumentation was designed to operate at a single frequency: typically, a standard system intermediate frequency (21.4, 30 MHz, etc.).

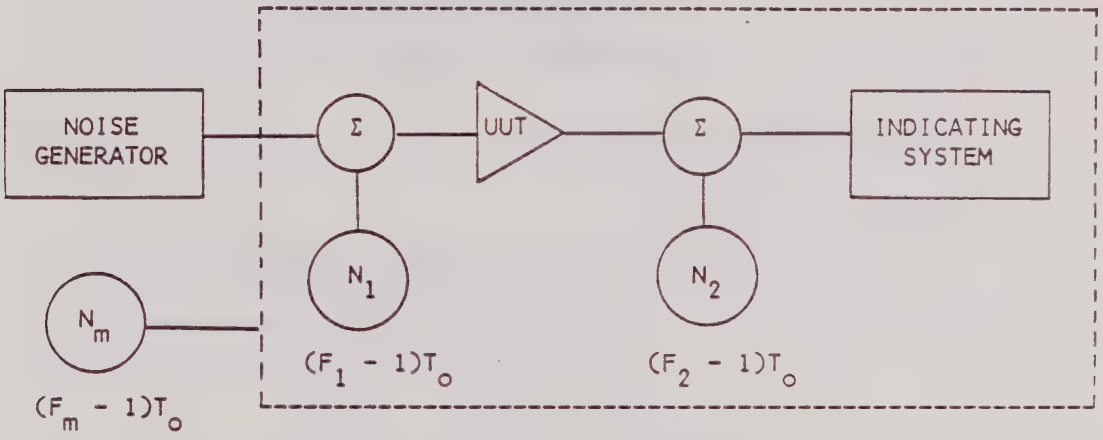
If the UUT operated at a different frequency, or covered a broad range of frequencies, the user was required to assemble an external conversion system (mixer, preamplifier and local oscillator) as part of the measuring system. This, of course, generated additional questions on image response and second stage noise.

ENR Variation With Frequency

The world is not flat, and neither are noise generators. Particularly, the solid state noise sources in general use today. An AILTECH instrument was the first to provide an output indication compensated for the actual ENR of the noise generator (as opposed to one based on a single, nominal ENR). However, the instrument needed to be readjusted each time the measurement frequency changed.

Second Stage Noise

A complete measurement system consists of a noise generator, UUT, and an indicator system. The indicated noise parameter will be that of the overall setup including the indicator. Obviously, the desired result is the noise performance of the UUT alone. The situation is illustrated below.



The measured result is:

$$F_m = F_1 + \frac{F_2 - 1}{G_1} \qquad (7)$$

The desired result is:

$$F_m = F_1 + \frac{F_2 - 1}{G_1} \qquad (7)$$

To summarize:

Receiver noise parameter measurement accuracy and convenience can be affected by:

- INDICATOR INPUT FREQUENCY
- IMAGE RESPONSE
- TERMINATION TEMPERATURE
- ENR FREQUENCY RESPONSE
- SECOND STAGE NOISE

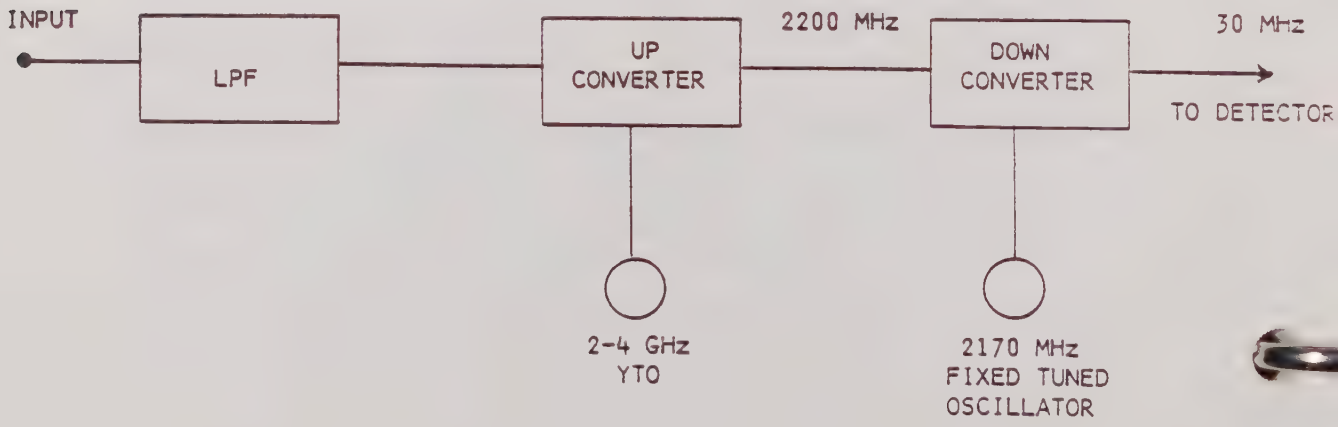
IV. THE 2075 APPROACH TO SOLUTIONS

The 2075 incorporates a:

- General management processor
- Arithmetic processor
- Display processor
- Bus management processor

While all the problems are not solved by internal computing capability (e.g., image response and frequency range), it should be noted that the circuitry providing the solutions is microprocessor driven which provides a high degree of precision.

o A broad, tunable frequency range is provided by means of a modification of a standard low frequency spectrum analyzer technique:



The YIG tuned oscillator with a microprocessor controlled driver provides fast, precise, convenient pushbutton selection of input frequencies between 10 and 1800 MHz. The microprocessor can cause the YIG oscillator to step at selected frequency intervals over all or any part of that band, thus providing a "swept" capability.

- Confusion over image response corrections can be eliminated by:

    1. Eliminating the image response.
    2. Making "double-sideband" measurements and recognizing them as such.

  The 2075 provides both options.

  In the 10 to 1800 MHz range, the input low pass filter and up/down conversion scheme effectively remove the image. This is particularly important in the UHF-VHF range where broadband amplifiers may exhibit considerable noise and gain variation over their passband.

  The high input frequencies available simplify removing the image from microwave amplifier measurements.

- ENR frequency response is taken care of by providing means to enter up to 93 ENR versus frequency data points in non-volatile RAM. The data are segregated into three selectable tables, each with 31 data points. An optional ROM can be provided with an additional 31 ENR/frequency values for an available total of 124 data points. In addition, there is a default table which sets the ENR at all frequencies to a nominal value.

  More often than not, the measurement frequency will not coincide with an ENR calibration data point. The 2075 firmware incorporates a sub-routine that linearly interpolates ENR at measurement frequencies between calibration points.

- Termination temperature errors are eliminated through use of the more exact equation for noise figure (3) in the firmware and allowing entry of the actual cold termination temperature. If no temperature is entered, the

instrument will default to 296 K (approximately 74°F). Temperature can be entered in kelvins, degrees Centigrade, or Fahrenheit.

- Second stage noise contribution has, especially in the past few years, become an annoying aspect of noise performance measurements. As can be seen from the equations presented earlier, as the gain and noise figure of the UUT gets lower, the contribution of the measuring system to the measured noise figure becomes more significant. For example, if:

$$F_1 = 2 \text{ dB}$$
$$F_2 = 10 \text{ dB}$$
$$G_1 = 6 \text{ dB}$$

then the measured noise figure, $F_m = 5.84$ dB.

The parameters are quite typical of a microwave amplifier measurement.

The sensitivity of the instrument is such that it can measure its own noise figure or, for that matter, the noise figure of a lossy element (such as a mixer). This permits measurement and storage of second stage noise figure versus frequency. These data, in conjunction with the gain measurement capability, are then used to provide on-line computation of true, UUT noise performance.

V. OTHER FEATURES

In many applications, it is desirable to measure the noise performance of an amplifier or receiver in terms of effective input noise temperature (T_e). Typical of this is the specification on low noise amplifiers used in satellite earth stations. The second stage of such receiving systems are, however, generally specified in terms of noise figure; thus, it would be convenient to be able to switch easily from one parameter to the other.

The 2075 has this feature on the front panel. Special functions are not required.

System noise calculations require that noise figure and gain be expressed as ratios. Again, this is easily accomplished from the front panel of the 2075.

Other measurement parameters, not utilized to the degree of those mentioned above are available in the Special Function menu. Among these are:

- Y-factor
- Operating Noise Temperature
- Noise Measure (M)
- Noise Power (relative to reference noise)

VI. MEASUREMENTS ABOVE 1.8 GHz

The 2075 incorporates provision for the five UUT configurations operating above 1.8 GHz. These are:

- Amplifier - Swept LO mode
- Amplifier - Swept IF mode
- Converter - Swept LO mode
- Converter - Swept IF mode
- Dual Converter - Swept LO mode

The configurations using the swept LO mode require a GPIB controllable signal source. This can be driven on the bus by the 2075 and does not require an external controller.

VII. CONCLUSIONS

The 2075 represents a significant step forward in simplifying accurate receiver/amplifier measurements.

In a non-automated setup, it relieves the user of the chore of assembling external equipment for broadband measurement. It can also save the user

hours of off-line calculation time previously required for correcting measured results (second stage noise, ENR, etc.).

In a computer-controlled setup, it simplifies the software task through local implementation of such things as:

- ENR interpolation
- Second stage noise calculation
- Reference temperature compensation
- Frequency stepping
- Conversion to other parameters

The Impact of Microprocessors on RF/Microwave Receiver/Amplifier Noise Measurements

Measuring the noise performance of RF and microwave receivers is a difficult task using conventional instruments. However, microprocessor-based instruments are eliminating the need for manual calculations and secondary measurements.

William E. Pastori,
Director of Marketing, Eaton Corporation
Electronic Instrumentation Division

Until recently, measuring RF and microwave receiver noise parameters, such as noise figure, effective input noise temperature and operating noise temperature, required the use of classical analog measuring instruments. Certain characteristics of these instruments required the user to do some "off-line" manipulation of the data in order to obtain an accurate, fully-corrected result. These calculations typically involved: corrections for image response, second-stage noise and reference (cold) temperature; noise generator excess noise ratio variations with frequency; loss compensation; and conversion to other noise parameters. Since one facet of a microprocessor is data manipulation, it lends itself to "on-line" calculation and potential time savings when applied to noise parameter instrumentation.

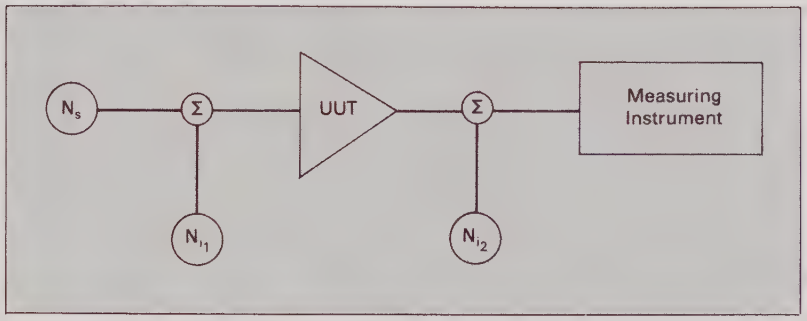


FIGURE 1. This model for noise performance factor measurements shows the points (marked N) at which calculations are necessary to obtain the output noise power of thermal or equivalent thermal noise sources.

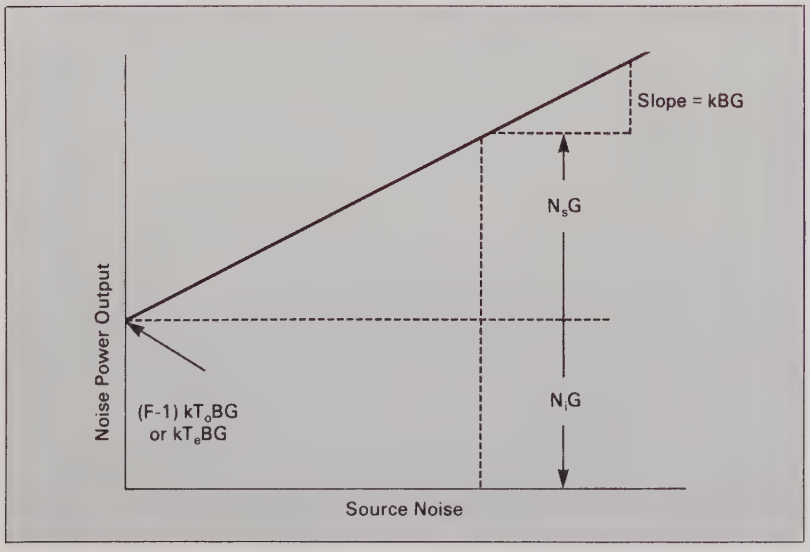


FIGURE 2. A plot of the noise power output of a transducer has a slope that is a function of the transducer gain.

Evaluating Noise Performance

The noise generated within RF and microwave receivers is the inherent limiting factor in the ability of the receiver to extract intelligence from remotely generated signals over most

of the currently occupied frequency spectrum. In effect, this limit determines receiver sensitivity.

Receiver/amplifier noise performance factors, such as noise figure[1] (or noise factor) and effective input noise temperature[2] describe the internal noisiness of the transducer, including the complete receiver, amplifier, transistors and so on.

It is not possible to measure these noise performance factors directly. Instead, they are calculated from the results of what is commonly termed a Y-factor measurement. However, the simple application of the basic relationship between Y-factor and the noise performance factors, either manually or via instrumentation, can yield results which differ significantly from the actual noise performance of the transducer.

Evaluation of the effects of such factors as measurement system noise contribution (second stage noise), room temperature deviations from the standard reference temperature, noise generator output variation with frequency, image response and loss compensation involves considerable auxiliary measurement and off-line calculations.

This dependence on calculation and secondary measurement makes the evaluation of receiver noise performance factors an ideal environment for the application of both computing and control microprocessors to the instrumentation.

Basic Considerations

Measurement of noise figure or effective input noise temperature can be illustrated by the noise model shown in Figure 1. Here, the circles enclosing a subscripted letter "N" represent thermal or equivalent thermal noise sources whose available output noise power is given by:[3]

$$N = kTB \quad (1)$$

where:

k = Boltzmann's constant (1.38×10^{-23} joules/kelvin)
T = Temperature on the absolute (Kelvin) scale
B = Bandwidth

The unit-under-test (UUT) and the measurement system are both replaced by noiseless equivalents, with the internal noisiness of each represented by fictitious thermal noise sources referenced to each input.

In simplified form, noise figure can be described as the ratio of the actual noise power output of a transducer to that of an ideal noiseless transducer of otherwise identical characteristics when the source termination is at the standard reference temperature, 290 K (T_o).[4] From Figure 1, for the UUT alone:

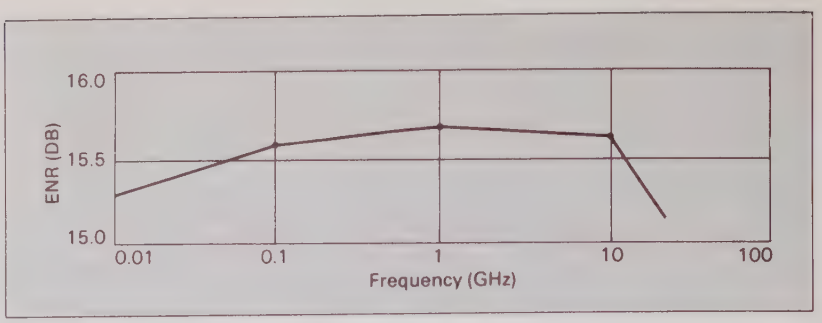


FIGURE 3. This chart shows a plot of ENR versus frequency of a typical, commercially-available noise generator.

$$F = \frac{G_1 (N_o + N_{i_1})}{G_1 N_o} \quad (2)$$

$$N_{i_1} = (F_1 - 1)\, kT_oB \quad (3)$$

Effective input noise temperature can be described as the temperature of the equivalent thermal noise source representing the internal noisiness of the transducer:

$$N_{i_1} = kT_{e_1}B \quad (4)$$

Similarly for the measuring instrument:

$$N_{i_2} = (F_2 - 1)\, kT_oB = kT_{e_2}B \quad (5)$$

and the overall noisiness of the combination:

$$N_{i_T} = (F_T - 1)\, kT_oB = kT_{e_T}B \quad (6)$$

The preceding equations show that the noise power output of a transducer as a function of source noise is a plot of a simple straight line whose y-intercept is a function of the noise performance factors and whose slope is a function of the transducer gain. Figure 2 illustrates this process.

FIGURE 4. A test set-up incorporating a microprocessor-controlled noise measuring instrument simplifies measurements at microwave frequencies above the upper frequency limit of the instrument.

Measurement Procedure

To determine noise performance factors involves the successive application of two known source termination temperatures to the transducer input, and measurement of the ratio of the resultant transducer noise output powers. Note that measurement of the noise power output ratio (Y-factor) precludes having to measure the absolute values of the noise powers. Generally:

$$Y = \frac{N_{o_H}}{N_{o_C}} = \frac{GkT_HB + G(F - 1)kT_oB}{GkT_CB + G(F - 1)kT_oB} \quad (7)$$

and,

$$F = \frac{R - Y\,\frac{T_C - 1}{T_o}}{Y - 1} \quad (8)$$

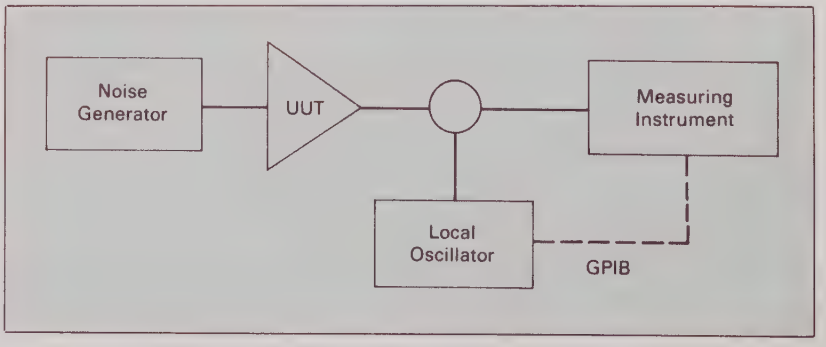
where:

$$R = \frac{T_H}{T_o} - 1 \quad (9)$$

This last term is generally referred to as the excess noise ratio or ENR of the noise generator.

Effective input noise temperature can be determined from:

$$T_e = \frac{T_H - YT_C}{Y - 1} \quad (10)$$



In addition, note that if the cold source termination temperature is equal to the standard reference temperature, T_o (290 K), then:

$$F = \frac{R}{Y - 1} \qquad (11)$$

Cold Source Termination Temperature Errors

In most laboratory and production measurement situations, the cold source termination temperature is simply room temperature. Quite often the assumption is that room temperature equals the standard reference temperature, 290 K, and either the operator or the instrumentation calculates noise figure using the simplified relation, Equation 12. However, 290 K is approximately equal to 62° F and, obviously, this assumption and procedure introduces an error in the measurement result. The error becomes significant when the measured noise figure is small, and decreases at higher noise figures. For example, if:

$$T_C = 300K$$
$$F = 1.9dB \qquad (12)$$

then the simplified calculation will be in error by +0.1 dB.

UUT/Noise Generator Interface Loss

The insertion loss of components such as cables and adapters inserted between the noise generator and the UUT will change the applied source termination temperature as indicated by Figure 3 and Equation 13.[5]

$$T' = nT_s + (1-n)T_L \qquad (13)$$

Since the loss is dissipative, it will generate thermal noise, and the output noise temperature of the system is, in general, not simply the attenuated output of the source, T_s.

Noise Generator Output Frequency Response

The ENR of most noise generators used for laboratory and production measurements of noise performance factors exhibits significant variations as a function of frequency. This change is particularly true of solid-state generators which are often rated for operation over more than three decades.

As indicated by Equations 8, 11 and 12, calculations must account for this variation to insure an accurate indication of noise figure or effective input noise temperature. The error, in dB, in the calculated value of noise figure resulting from an incorrect ENR is approximately equal to the error in the ENR.

Second Stage Noise Contribution

As noted in the earlier sections, the measurement system itself contributes to the measured noise performance. From Figure 1 and Equations 2 through 6:

$$N_{o_T} = [(N_s + N_{i_1})G_1 + N_{i_2}]G_2 \qquad (14)$$

However,

$$N_{o_T} = (N_s + N_{i_T})G_1G_2 \qquad (15)$$

Therefore,

$$N_{i_T} = N_{i_1} + \frac{N_{i_2}}{G_1} \qquad (16)$$

and,

$$F_T = F_1 + \frac{F_2 - 1}{G_1} \qquad (17)$$

In Equation 17, F_T represents the noise figure of the overall cascade including the measurement system — the value that would be calculated from a direct measurement of Y-factor. F_2 represents the noise figure of the measuring instrumentation, and F_1 represents the noise figure of the UUT alone.

The resulting error can be significant for low noise, low gain transducers; for example, if:

$F_1 = 1.6$ (2dB)
$F_2 = 10$ (10 dB)
$G_1 = 10$ (10dB)

Then F_T, the measured noise figure, would be about 2.5 or 4 dB.

The Microprocessor Based Instrument

The basic calculation of noise performance factors of RF and microwave amplifiers and receivers from a Y-factor measurement is relatively simple — particularly when using the simplified equation, which assumes that the noise generator cold temperature is equal to the standard reference temperature, for the calculation.

The preceding sections of this article show that simplistic calculation of noise performance factors from a Y-factor measurement can yield a result which is significantly in error. These potential errors include:

- Cold termination temperature error,
- UUT/noise generator interface loss,
- Noise generator ENR frequency response,
- Measurement system (second-stage) noise contribution.

All of these errors occurred because of the difficulty of handling the required calculations in analog instruments; therefore, the need for approximations. As noise performance of transducers dropped to the levels experienced at present, however, the need for higher accuracy required considerable "off-line" calculation to correct the results for these effects (in many cases the magnitude of the corrections exceeded that of the factor under measurement.)

Advances in microprocessor technology and software development as well as circuit cost reductions over the past several years make it possible to not just correct for these effects, but, in most cases, avoid the errors entirely.

For example, the use of the more general equation [8] to calculate noise figure and having the operator enter actual cold source temperature as a parameter of the operation make it possible to effectively eliminate the cold source termination temperature error. In addition, it is possible to handle losses in the measurement setup in the same manner. And because of the computing power available, the operator can enter loss temperature if it happens to be different from the cold source temperature.

Microprocessor-based instruments can also store noise generator ENR versus frequency data in non-volatile memory, with the computer interpolating between calibration points to further improve accuracy when the measurement frequency does not coincide with a calibration point (as is usually the case). The noise performance of the measurement system itself can be measured and stored, and the stored values used in correcting for "second-stage noise" contributions. This feature, available in newer instrumentation, requires that the measurement system be sufficiently sensitive to measure its own noise performance.

Other Features

The problem of image response correction is still a factor in accurate

RF and microwave receiver measurements. Although work is currently underway to solve this problem, a considerable amount of confusion still exists in the industry over this effect.

As noted in the reference, the simplest means of avoiding these complications is to eliminate the image response, or to make measurements that include and recognize the image. While eliminating the image from the measurement is more a function of the front end design of the instrument, it should be noted that the control microprocessor provides the tuning control and precision.

The existence of the microprocessor also simplifies measurements at microwave frequencies above the upper frequency limit of the instrument. A typical amplifier measurement setup, directly under the control of the processor, simplifies the measurement and effectively aids in removing the image response:

- The tuning precision afforded by the microprocessor permits use of a very high IF (up to about 1800 MHz). This, in turn, puts a very wide frequency separation between the signal and image responses simplifying filtering of the latter.
- The operator selects the RF and the fixed IF and enters the sideband to be measured (upper or lower). The microprocessor, via the GPIB, drives the local oscillator to a frequency correctly offset in the appropriate direction from the desired measurement (RF) frequency.
- At each measurement frequency, the processor determines the correct ENR by means of the previously entered calibration data and the linear interpolation routine.

Conclusions

Prior to the advent of the microprocessor as a viable element of a measuring instrument, instrumentation designed to measure receiver/amplifier noise performance factors was essentially incapable of providing a precise, accurate readout of the result. This situation existed because of the complexity of the calculation of noise performance factors, and the many variables that affected measurement accuracy.

The measurement requirement is an ideal environment for an embedded microprocessor. It permits entry of the variables and can handle the required calculations with relative ease as well as providing other control functions.

The net result is a new class of instrument which permits selection of the readout parameter (noise figure, effective input noise temperature, etc.), provides a more accurate result and simplifies the measurement.

REFERENCES

1. "IRE Standards on Electron Tubes: Definitions of Terms, 1957, (57 IRE 7.52)," Proc. IEEE, Vol. 45, July 1957, pp. 983-1010.

2. "IRE Standards on Electron Tubes: Definitions of Terms, 1962, (62 IRE 7.52)", Proc. IEEE, Vol. 51, March 1963, pp. 434-435.

3. J.B. Johnson, "Thermal Agitation of Electricity in Conductors," *Physical Review*, Vol. 32, July 1928, p. 97.

4. W.E. Pastori, "A Review of Noise Figure Instrumentation", *Microwave Journal*, April 1983.

5. A. Van der Ziel, *Noise*, New York: Prentice-Hall, 1954.

6. W.E. Pastori, "Image and Second-Stage Corrections Resolve Noise Figure Measurement Confusion", *Microwave Systems News*, Vol. 13, No. 5, May 1983.

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HIGH ACCURACY NOISE FIGURE MEASUREMENTS

PRESENTED AT MTT ONE-DAY SHORT COURSE SEMINAR
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I. INTRODUCTION

The primary limitation to the sensitivity of receiving systems operating in the most heavily populated segment of the electromagnetic frequency spectrum is the electrical noise generated within the receiver itself. This is illustrated by Figure 1 which plots the noise temperature (related to"sky" noise) of an ideal, vertically-oriented antenna versus frequency[1]. This well-publicized "bathtub" curve indicates excellent external noise conditions between 500 MHz and about 12 GHz.

The concept of noise figure (or noise factor) provides a means of evaluating and characterizing the internal noisiness of receivers. Noise figure can also be used to relate the noise performance of individual receiver elements (low-noise amplifiers, converters, etc.) to overall receiver performance; thus, it is a "common language" for specifying and evaluating the noise characteristics at all vertical levels of receiver manufacture from the complete system down to individual devices (transistors, FETs, mixer diodes, etc.).

One illustration of the importance of noise figure is provided by Figure 2. This is a plot of the effective radiated power from a satellite versus receiver noise figure required for unit signal to noise ratio at the earth station receiver terminals for a typical satellite communication system. As can be seen, an error of just a few tenths of a dB in the evaluation of the earth station receiver noise figure could result in an overdesign of the satellite transmitter by several watts: an important economic design factor particularly for spaceborne applications.

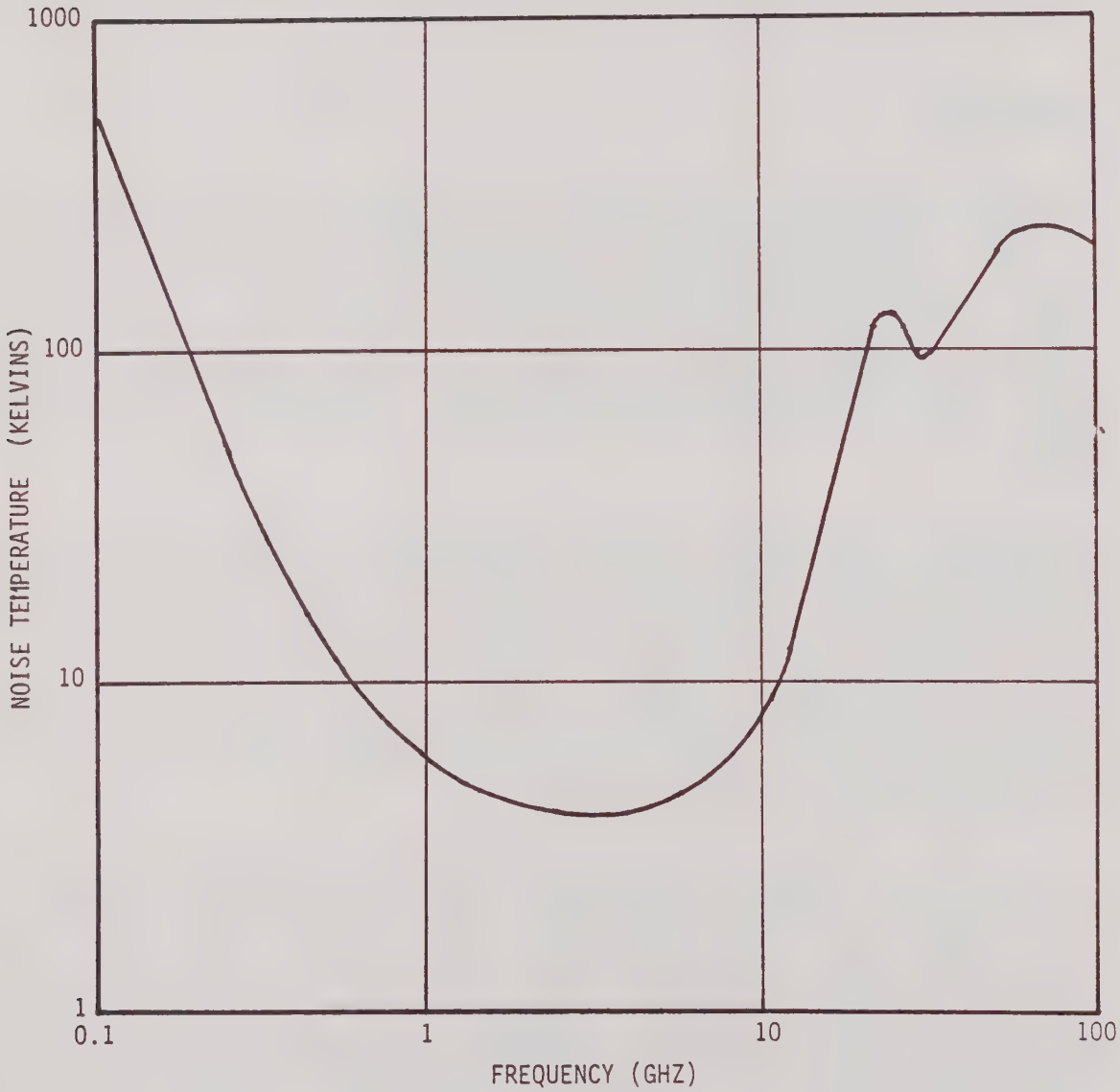

FIGURE 1. PLOT OF IDEAL ANTENNA NOISE TEMPERATURE vs. FREQUENCY

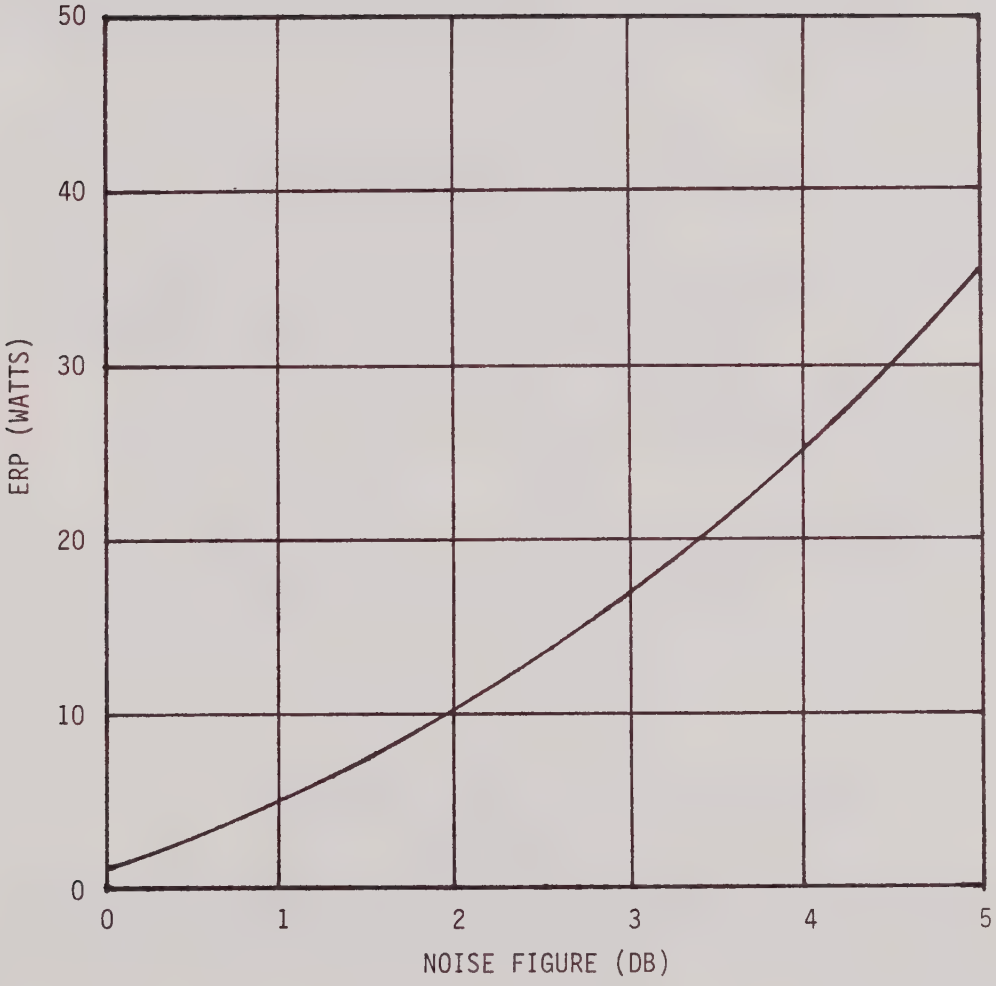

FIGURE 2. EFFECTIVE RADIATED POWER vs. NOISE FIGURE FOR S/N = 1

II. BASIC CONSIDERATIONS

Thermal Noise

Noise in receiving systems is usually characterized in terms of thermal noise; that is, the noise resulting from the random motion of charge carriers within a conductor - this random motion being a function of the physical temperature of the conductor. Thermal noise can be expressed in terms of the open circuit noise voltage appearing across the terminals of a resistor [2,3].

$$\overline{e_n}^2 = 4kT \int p(f)\, R(f) df \qquad (1)$$

where,

k = Boltzmann's Constant (1.38×110^{-23} joules/K)
T = temperature (expressed on the absolute scale)
$R(f)$ = resistance
$p(f)$ = Planck's Factor

Since, for most practicial situations:

$R(f)$ = R (constant over the observed frequency range)
$p(f)$ = 1

then,

$$\overline{e_n}^2 = 4kTRB \qquad (2)$$

where, B = bandwidth

Available Noise Power

In RF and microwave systems it is more common, and in fact more appropriate to consider noise power rather than noise voltage or current. Because the receiver element is often deliberately mismatched, the expressions are usually in terms of available power.

Available power is defined as the power that a source network would deliver to a perfectly matched load. From Equation 2, the noise power available from a thermal source is given by:

$$P_N = \frac{\overline{e_n^2}}{4R} = kTB \qquad (3)$$

The General Noisy Tansducer

The noise performance of a transducer (any device or system with a definable noise figure) can be evaluated in terms of the simple model shown in Figure 3. The transducer is replaced by its noiseless equivalent, and the internally generated noise is represented by an equivalent thermal noise source referred to the input of the transducer. Source termination noise is also represented as a thermal noise source.

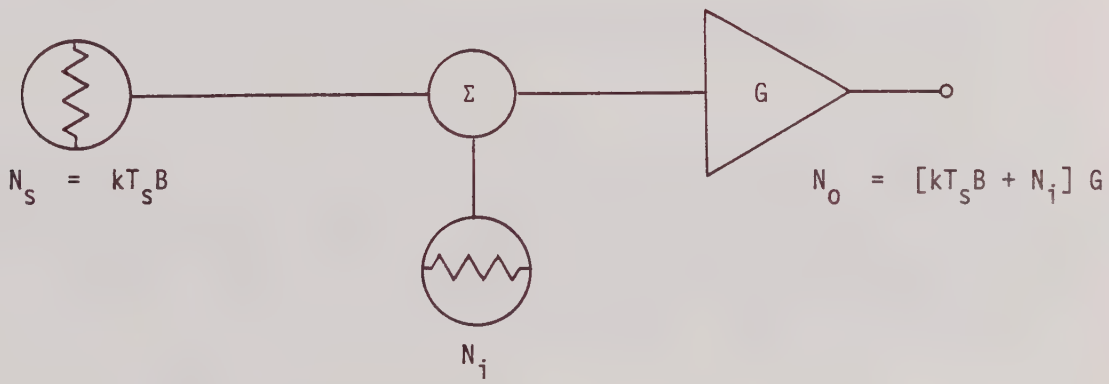

FIGURE 3. THE GENERAL NOISY TRANSDUCER

As can be seen from Figure 3, the noise output power of the transducer is a simple, straight-line function of source termination noise:

$$N_o = (kT_SB + N_i)\ G \qquad (4)$$

where, N_o = available noise power at the transducer output
T_S = source termination temperature
N_i = noise power generated within the transducer referred to the input
G = available gain of the transducer

Noise Figure

Noise figure of a transducer is defined[4] at a specified input frequency as the ratio of:

1. that total noise power per unit bandwidth at a corresponding output frequency available at the output port when the noise temperature at the input is standard (290 K) at all frequencies to

2. that portion of 1. engendered at the input frequency by the input termination at the standard noise temperature, 290 K.

Note that 2. includes only that portion of the source termination noise that appears at the output via the principal signal frequency transformation.

This last statement is an important consideration in the evaluation of heterodyne devices and systems, and has given rise to considerable confusion in the past[5]

In somewhat simpler terms, noise figure can be expressed as the ratio of the actual noise output power of the transducer to that of an ideal noiseless transducer of otherwise identical characteristics when the source termination is at the standard reference temperature, T_o (290 K)[6]. If we ignore image response complications, then from Figure 3 and Equation 4:

$$F = \frac{N_{act}}{N_{ideal}} = \frac{(kT_oB + N_i)\,G}{kT_oBG} \tag{5}$$

$$N_i = (F - 1)\,kT_oB \tag{6}$$

Equation 6 defines the effective temperature of the equivalent thermal noise source representing the internal noisiness of the transducer:

$$T_e = (F - 1)\,T_o \tag{7}$$

T_e is referred to as the effective input noise temperature[7] of the transducer and is often specified for very low noise transducers in place of noise figure.

Combining (6) and (4):

$$N_o = [T_s + (F - 1)T_o] kBG \quad (8)$$

As noted earlier, a plot of transducer noise output power versus source temperature is a straight line of the form:

$$y = mx + b \quad (9)$$

As can be seen from Figure 4 and Equation 8, the y-axis intercept is a function of noise figure, while the slope of the line is a function of the gain-bandwidth product; therefore, in order to determine noise figure, it is only necessary to establish two points on the line.

III. MEASUREMENT TECHNIQUE

Since noise figure is a figure of merit rather than a physical entity, an indirect method of measurement must be used. There are several means by which the quantity can be determined; however, these differ primarily in implementation. In general, noise figure is calculated from the results of what is usually referred to as a "Y-factor" measurement[8].

Noise figure can be determined by successive application of two, known source termination temperatures to the transducer input, and measurement of the ratio of the resultant transducer noise output powers (Y-factor). Note that measurement of the noise power output ratio precludes having to measure the absolute values of the noise powers - a difficult measurement to perform accurately.

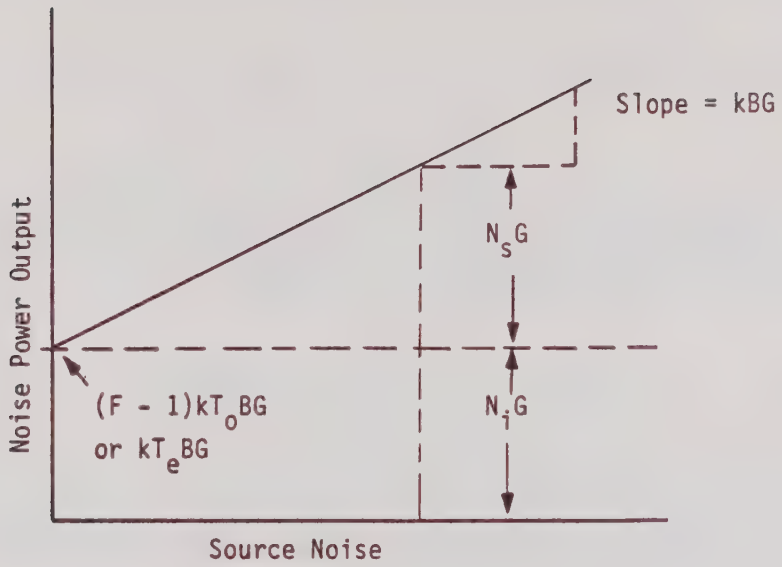

FIGURE 4. GRAPHICAL REPRESENTATION OF TRANSDUCER NOISE POWER OUTPUT versus SOURCE TERMINATION NOISE

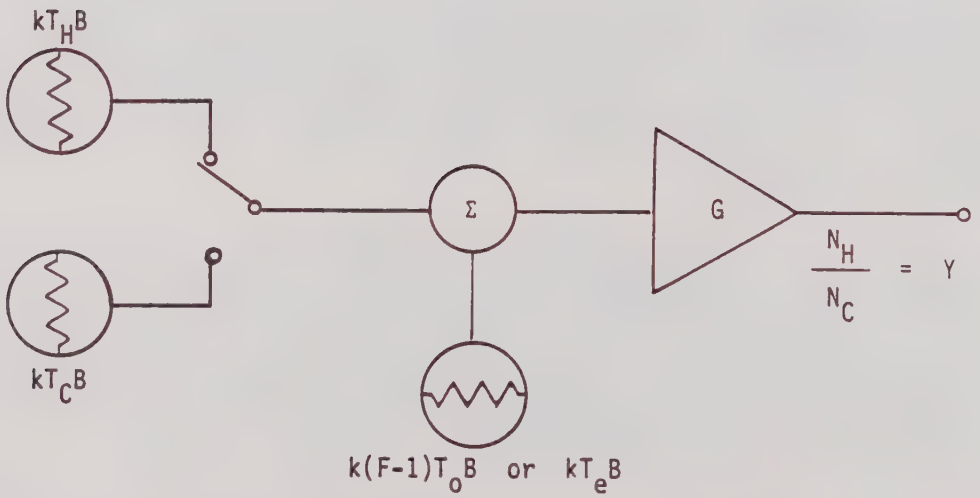

FIGURE 5. SIMPLIFIED MEASUREMENT BLOCK DIAGRAM

From Figure 5 and Equation 8:

$$Y = \frac{N_{o_H}}{N_{o_C}} = \frac{[T_H + (F-1)T_o]\, GkB}{[T_C + (F-1)T_o]\, GkB} \qquad (9)$$

and,

$$F = \frac{R - Y\left[\frac{T_C}{T_o} - 1\right]}{Y - 1} \qquad (10)$$

where,

$$R = \frac{T_H}{T_o} - 1 \qquad (11)$$

The quantity R, defined by Equation 11 is referred to as the excess noise ratio (ENR) of the noise generator.

IV. MEASUREMENT COMPLICATIONS

Superficially, the measurement and calculation of noise figure seems simple and straight forward; however, there are some practical aspects to the measurement which, if not accounted for, can introduce significant errors. Factors which should be considered are:

- Image response
- Cold source termination temperature error
- Loss between the noise generator and the unit-under-test
- Measurement system noise contributions

In general, these factors can be accounted for, and the measurement results corrected for their effects.

Image Response

Note that the denominator of the ratio that defines noise figure includes only that source termination noise which appears at the output port via the principal frequency transformation.

Since, in a practical sense, the source termination (noise generator) used in a measurement will be broadband, this effect must be considered when evaluating a transducer exhibiting an image response - such as a mixer-preamplifier.

If an image response is considered in Equation 5:

$$F = \frac{(kT_oB + N_i)}{kT_oB}\left(1 + \frac{G_i}{G_s}\right) \qquad (12)$$

where, G_i = gain through the image channel
G_s = gain through the signal channel

Since most noise measurement systems are incapable of detecting the existence of an image response, the calculated noise figure may be in error by the gain factor shown in Equation 12.

An image response in either the measurement system or the operating system generally causes some confusion as to whether or not it should be accounted for since, in some instances (e.g., the measurement of broadband amplifiers), the true result depends upon how the transducer is used in the actual operating system[5].

Noise measurements, especially those over very broad frequency ranges, are "double sideband"; that is, the image is not considered and the result is recognized as including the image.

In some cases (e.g. measurements made over less than an octave), the image is filtered out.

V. COLD SOURCE TERMINATION TEMPERATURE

In most laboratory and production measurement situations, the cold source termination temperature is simply room temperature. Quite often, the assumption is made that room temperature is equal to the standard reference temperature, 290 K, and either the operator or the instrumentation calculates noise figure using the simplified relation, Equation 13.

If, $T_c = T_o$

Then, from Equation 10:

$$F = \frac{R}{Y-1} \tag{13}$$

However, 290 K is approximately equal to 62°F and, obviously, this assumption and procedure introduces an error in the measurement result. The error, becomes significant when the measured noise figure is small, and decreases at high noise figures. This is illustrated in Figure 6.

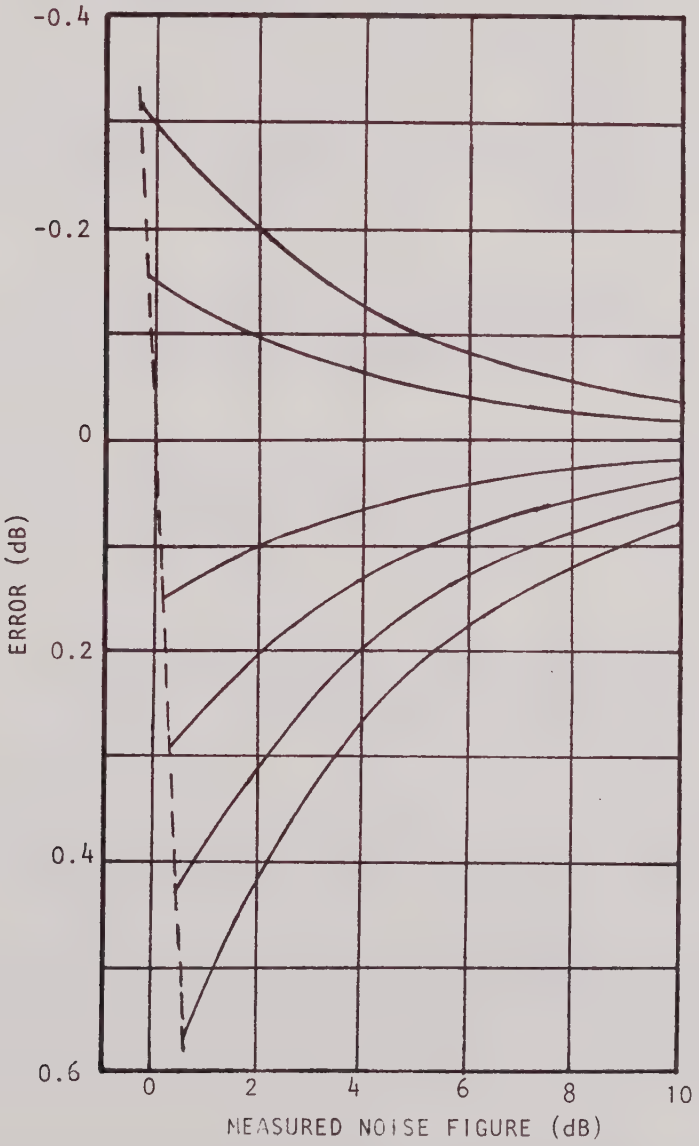

FIGURE 6. ERROR IN MEASURED NOISE FIGURE RESULTING FROM THE ASSUMPTION THAT $T_C = T_o$ (ENR = 15.3 dB)

VI. UTT/NOISE GENERATOR INTERFACE LOSS

The insertion loss of components such as cables and adapters inserted between the noise generator and the UUT will change the applied source termination temperature as indicated by Figure 7 and Equation 14[9].

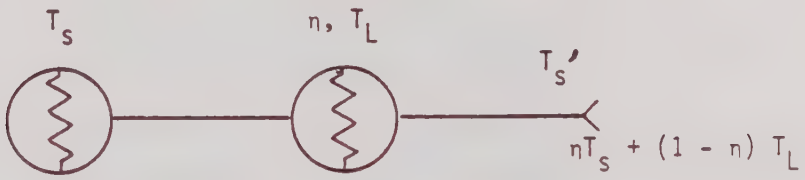

FIGURE 7. MODEL ILLUSTRATING THE EFFECT ON NOISE GENERATOR OUTPUT

$$T_s' = nT_s + (1 - n) T_L \tag{14}$$

where, T_L = temperature of the lossy element
n = transmission efficiency

The general practice is to simply subtract the loss in dB from the ENR expressed in dB. The error associated with this practice is small for low losses whose temperature is near 290 K; however, as illustrated by Figure 8, the error can be significant when the loss is large and/or the loss temperature deviates significantly from the standard reference temperature.

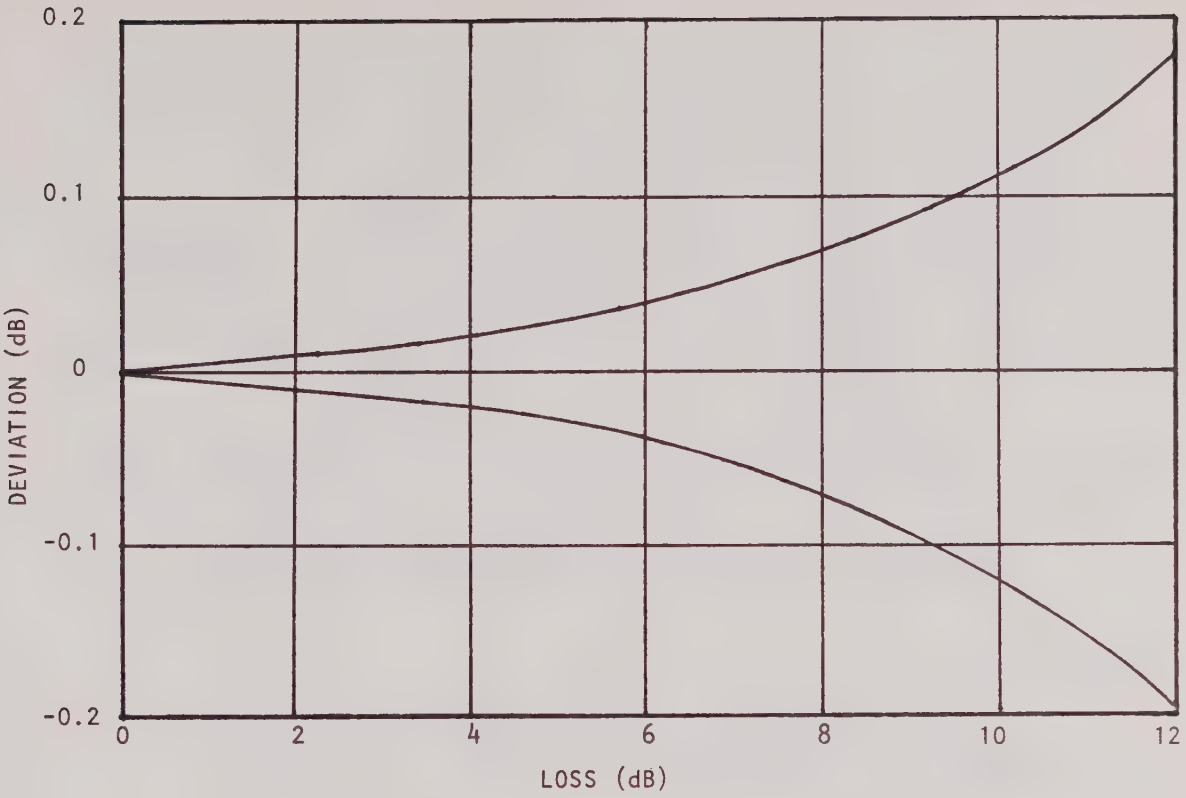

FIGURE 8. DEVIATION OF ACTUAL ENR FROM (ENR_{dB} - $LOSS_{dB}$) versus LOSS SHOWING THE EFFECT OF LOSS TEMPERATURE

VII. MEASUREMENT SYSTEM NOISE CONTRIBUTION (SECOND STAGE NOISE)

In Figure 5, some means must be provided to measure the Y-factor in order to determine noise figure. This is usually accomplished with some sort of receiving detection system which can either indicate noise figure directly (noise figure meter) or provide a readout of Y-factor by manual substitution (precision test receiver).

The indicating instrument also generates noise which contributes to the overall noise of the setup; however, it is the noise performance of the UUT alone that we are interested in.

Figure 9A is a block diagram of the overall setup showing individual noise contributions. Figure 9B is an equivalent which considers the setup a single entity with one noise figure - that which would be measured.

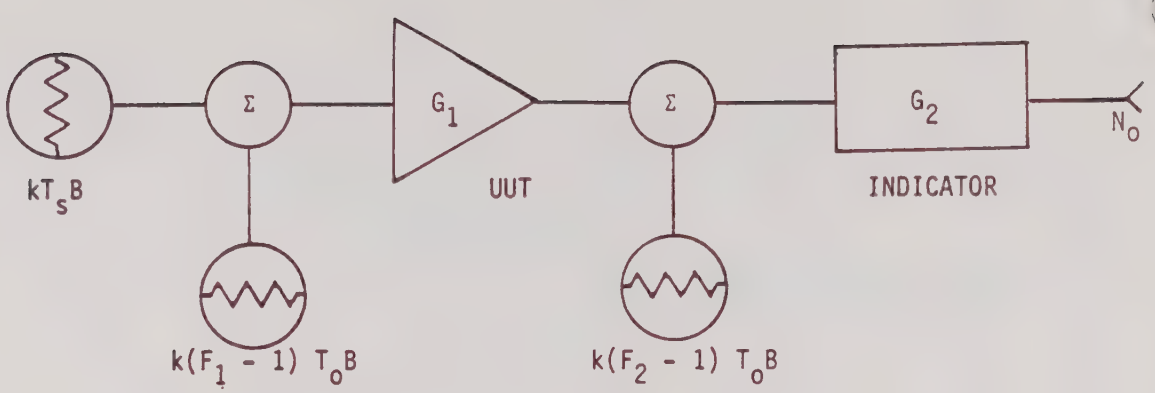

FIGURE 9A. MODEL SHOWING INDIVIDUAL NOISE CONTRIBUTORS

From Figure 9A:

$$N_o = kBG_2 \left\{(F_2 - 1)\ T_o + G_1\ [T_s + (F_1 - 1)\ T_o]\right\} \qquad (15)$$

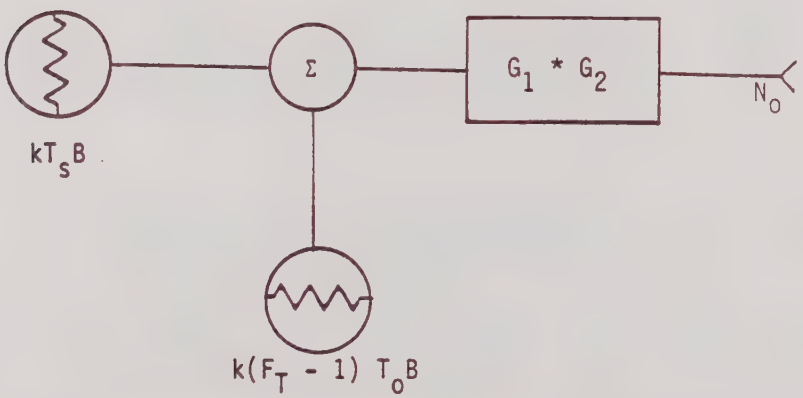

FIGURE 9B. OVERALL EQUIPMENT

FIGURE 9. MODELS USED TO DERIVE UUT AND INDICATOR NOISE FROM OVERALL MEASURED NOISE FIGURE

Similarly, from Figure 9B:

$$N_o = kBG_1G_2\ [T_s + (F_1 - 1)\ T_o] \qquad (16)$$

Equating 15 and 16:

$$F_1 = F_T - \frac{F_2 - 1}{G_1} \qquad (17)$$

In Equation 17, F_T represents the noise figure of the overall cascade including the measurement system - the value that would be calculated from a direct measurement of Y-factor. F_2 is the noise figure of the measuring instrument itself, and F_1 that of the UUT alone.

If not accounted for, the noise contribution of the measuring instrument can introduce a significant error in the measured results. This is illustrated by Figure 10 which shows a typical case:

$$\begin{aligned} F_1 &= 2 \text{ dB} \\ G_1 &= 17 \text{ dB} \\ F_2 &= 8 \text{ dB} \\ F_T &= 2.2 \text{ dB (measured noise figure)} \end{aligned}$$

A word of caution regarding the use of Equation 17 is in order. The derivation is based on the assumption that the measuring instrument noise bandwidth is less than or equal to the noise bandwidth of the UUT, that is:

$$B_2 \leq B_1 \qquad (18)$$

If this is not true, then Equation 17 must be modified as shown below:

$$F_1 = F_T - \left(\frac{F_2 - 1}{G_1}\right)\left(\frac{B_2}{B_1}\right) \qquad (19)$$

VI. RANDOM UNCERTAINTIES

The preceding section discussed potential inaccuracies due to assumptions and incomplete evaluation of the measurement system. These are correctable as noted.

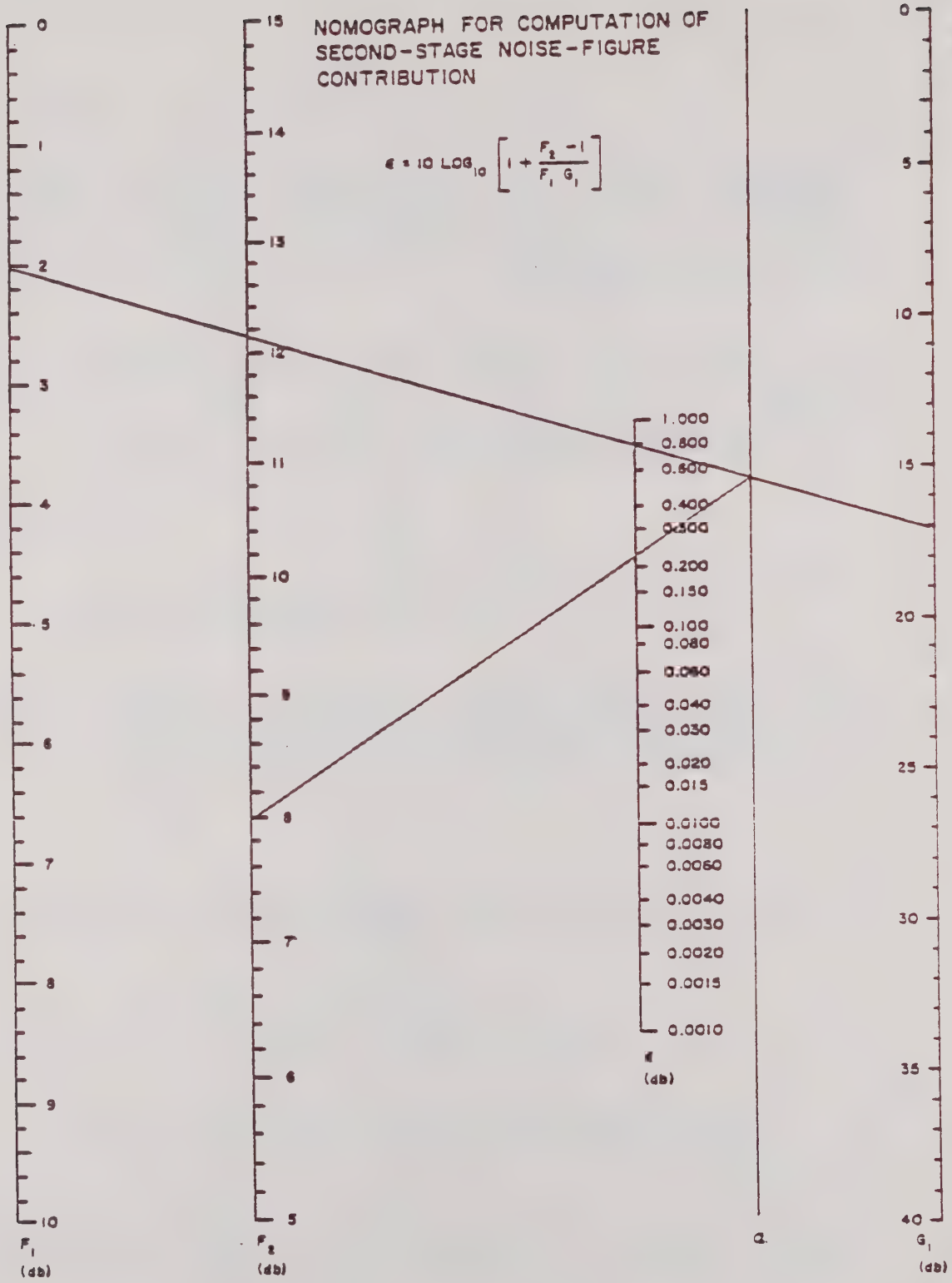
NOMOGRAPH FOR COMPUTATION OF SECOND-STAGE NOISE-FIGURE CONTRIBUTION
$\epsilon = 10 \log_{10} \left[1 + \frac{F_2 - 1}{F_1 G_1} \right]$
F_1 (db)
F_2 (db)
ϵ (db)
G_1 (db)
1.000
0.800
0.600
0.400
0.300
0.200
0.150
0.100
0.080
0.060
0.040
0.030
0.020
0.015
0.0100
0.0080
0.0060
0.0040
0.0030
0.0020
0.0015
0.0010

FIGURE 10.

In this section, the uncertainty of the measurement resulting from random errors in the basic parameters - T_H, T_C and Y - will be evaluated.

$$\Delta F = \left| \frac{\partial F}{\partial T_H} \right| \Delta T_H + \left| \frac{\partial F}{\partial F_C} \right| \Delta T_C + \left| \frac{\partial F}{\partial Y} \right| \Delta Y \qquad (20)$$

Taking the indicated derivatives:

$$\Delta F = \left| \frac{1}{T_o (F - 1)} \right| \Delta T_H + \left| \frac{1}{T_o \left(1 - \frac{1}{Y}\right)} \right| \Delta T_C + \left| \frac{B - R}{(Y - 1)^2} \right| \Delta Y \qquad (21)$$

where:

$$R = \frac{T_H}{T_o} - 1 \qquad (22)$$

$$B = \frac{T_C}{T_o} - 1 \qquad (23)$$

One conclusion that can be drawn from Equation 21 is that the overall uncertainty can be reduced by making:

$$Y >> 1$$

IX. HIGH ACCURACY TEST EQUIPMENT CAPABILITY

One means of reducing uncertainties in noise performance evaluations is to relate the measurement parameters (T_H, T_C, Y) to accurately known physical quantities. In the case of the source temperatures, this can be accomplished in practice through the use of true thermal noise sources whose temperatures can be directly related to well-established phenomena.

This philosophy is implemented in commercially available noise generators called Hot-Cold Standard Noise Generators, one of which is shown schematically in Figure 11.

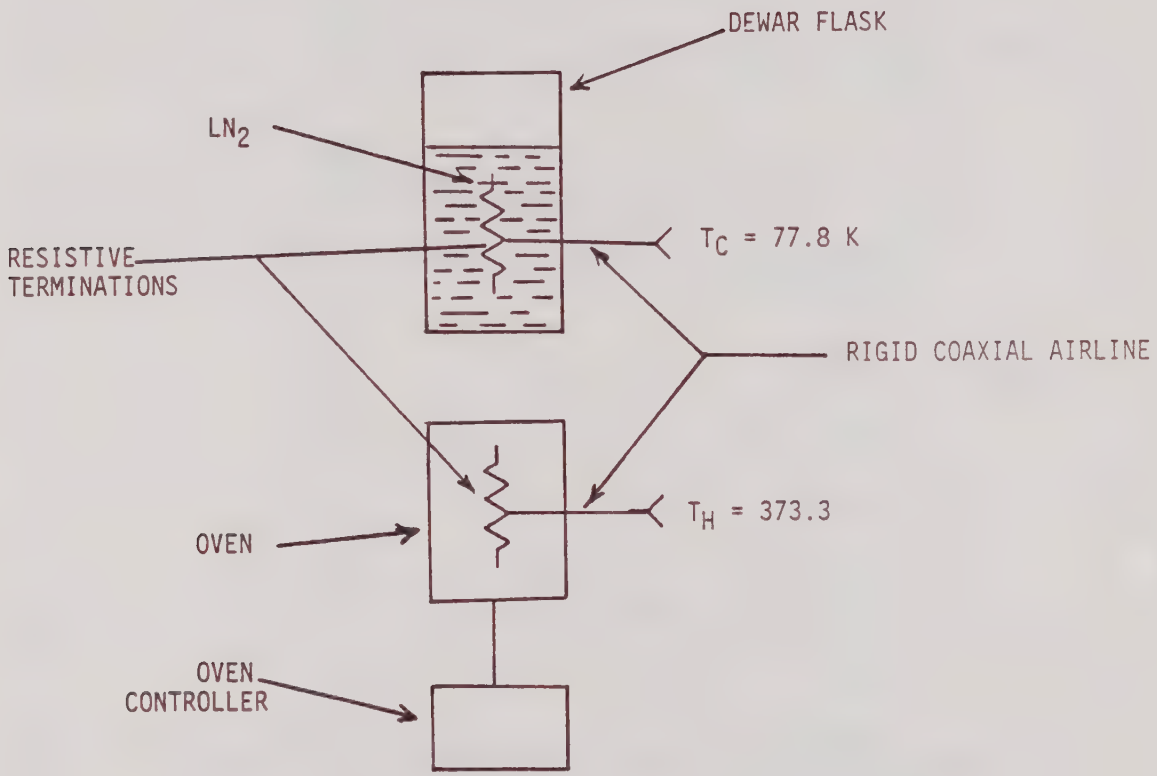

FIGURE 11. SCHEMATIC REPRESENTATION OF A TYPICAL THERMAL NOISE GENERATOR

A low reflection resistive termination is inserted into a DeWar flask filled with liquid nitrogen. This accurately establishes the temperature of the termination at that of boiling liquid nitrogen (78 K at sea level).

A second termination is enclosed in a precisely controlled oven calibrated against boiling water (373 K at sea level).

While this noise generation technique accurately establishes the two noise temperatures it should be noted that the temperature differential is rather small

compared to other methods. Unless the UUT is a very low noise device, this would cause the measured Y-factor to be small. As noted by Equation 21, this has a degrading effect on measurement uncertainty especially if:

$$Y < 2$$

Y-factor itself can be related to a physical measurement by means of the series attenuation substitution technique illustrated by Figure 12. When the hot source temperature is applied, attenuation is increased until the output indicator returns to the reference level noted when the cold source was applied. The change in attenuation is the Y-factor.

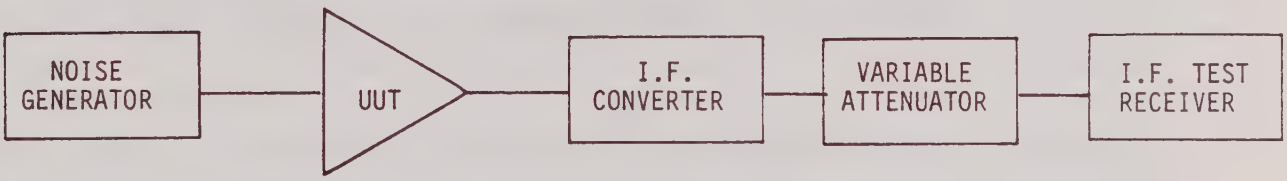

FIGURE 12. BLOCK DIAGRAM OF A SERIES ATTENUATION SUBSTITUTION SET-UP FOR MANUAL Y-FACTOR MEASUREMENTS

If the attenuator is a waveguide beyond cut-off type, the differential attenuation is directly related to:

1. the linear displacement between the launch and receive elements, and
2. the diameter of the circular waveguide.

Exclusive of mismatch effects, commercially available test equipment can achieve an overall measurement uncertainty of better than ±0.1 dB for low noise measurement.

X. LABORATORY/PRODUCTION MEASUREMENT

The techniques discussed in the preceding section are suitable for standards laboratories or one-time measurements; however, they are generally considered too cumbersome and time consuming where many measurements are required, such as in design engineering laboratories or production test applications.

In general, these environments make use of solid-state or gas discharge noise generators which can be keyed on and off (hot and cold) under control of a direct reading noise figure indicator. The effective hot temperature of such sources is typically in excess of 10,000 K. This insures a relatively large Y-factor even for noisy transducers. This disadvantage of such source is that it is difficult and costly to achieve ENR calibration uncertainties of better than ±0.2 dB (worst case).

There are a variety of indicators available with a wide range of direct reading accuracies (and prices); however, recently, microprocessor based instruments have made their appearance and offer convenience features and accuracies unavailable in the past.

Figure 13 is a simplified block diagram of a typical instrument. The embedded computing power is put to use in performing the basic noise figure calculation as well as correcting for the various complications discussed.

A major feature of such instruments is the high degree of linearity in the RF detector sections. Y-factor uncertainties of better than a few hundredths of a dB are common. At noise figures higher than 3-4 dB, these instruments can actually outperform the waveguide beyond cut-off attenuator technique.

In effect, the measurement uncertainty becomes almost solely a function of the noise generator calibration accuracy and mismatch effects.

As noted earlier, mismatch effects are difficult to evaluate; however, analyses[1] and empirical evaluations have shown that it is possible to achieve an overall root-sum-squared measurement uncertainty at microwave frequencies approaching ±0.2 dB.

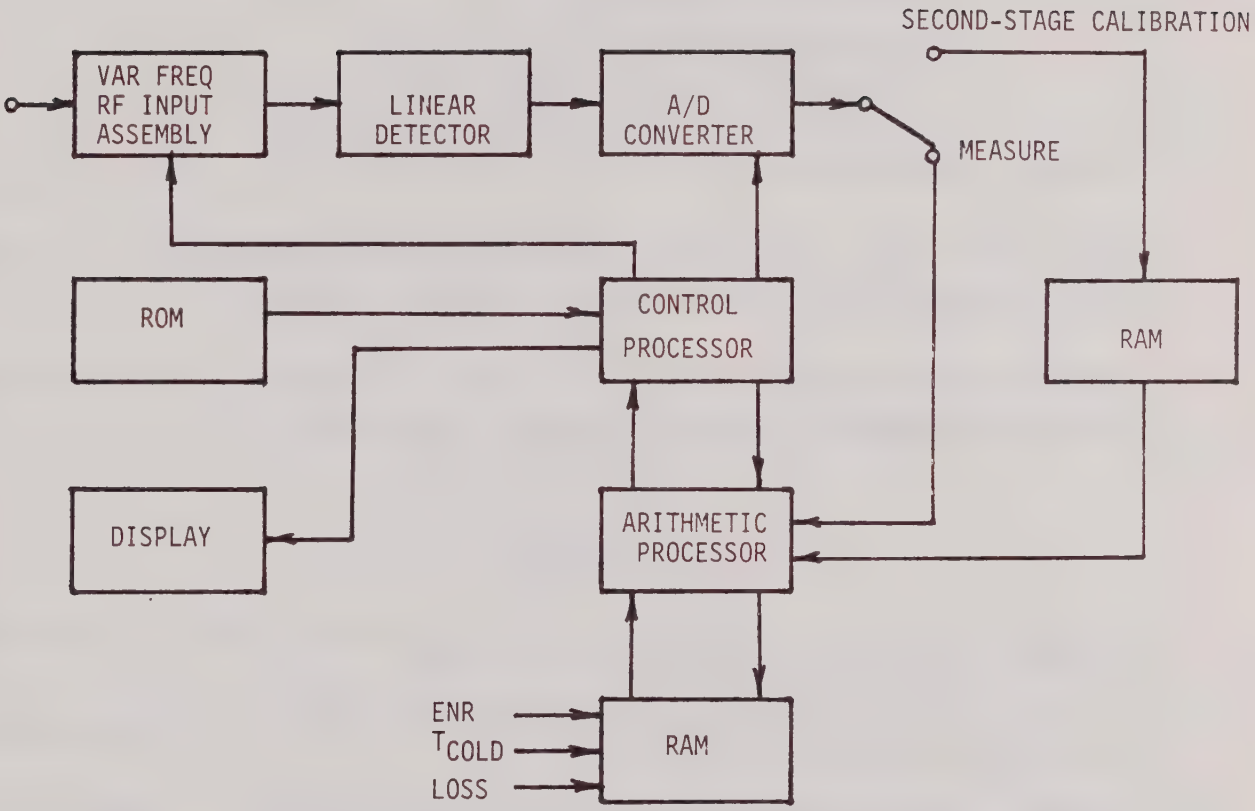

FIGURE 13. SIMPLIFIED BLOCK DIAGRAM OF A MICROPROCESSOR BASED RECEIVER NOISE ANALYZER

XI. CONCLUSIONS

Significant errors can occur in a noise figure measurement if care is not taken for such effects as:

- Measurement system noise
- Approximations based on $T_C = T_o$
- Loss between the noise source and the UUT

In general, these errors can be avoided or corrected.

High accuracy ($\Delta F_{dB} < \pm 0.1$ dB) can be achieved using techniques and equipment whose performance can be related to primary physical quantities.

The general laboratory or production test measurement can have a root-sum-squares uncertainty approaching ±0.2 dB at microwave frequencies.

REFERENCES

1. J.C. Greene, "Sensitivity Limitations Set by Ideal Antennas, Maser and Parametric Amplifiers", AIL Topics In Electronics, Vol. 2, 1961.

2. J.B. Johnson, "Thermal Agitation of Electricity In Conductors", Physical Review, Vol. 32, July 1928, p. 97.

3. H. Nyquist, "Thermal Agitation of Electric Charge In Conductors", Physical Review, Vol. 32, July 1928, p. 110.

4. "IRE Standards on Electron Tubes: Definitions of Terms, 1957 (57 IRE 7.52)", Proc. IEEE, Vol. 45, July 1957, pp. 983-1010.

5. W.E. Pastori, "Image and Second-Stage Corrections Resolve Noise Figure Measurement Confusion", Microwave Systems News, Vol. 13, No. 5, May 1983.

6. W.E. Pastori, "A Review of Noise Figure Instrumentation", Microwave Journal, April 1983.

7. "IRE Standards on Electron Tubes: Definitions of Terms, 1962 (62 IRE 7.52)", Proc. IEEE, Vol. 51, March 1963, pp. 434-435.

8. H.A. Hans, et. al., "Description of the Noise Performance of Amplifiers and Receiving System", Proc. IEEE, Vol. 51, March 1963, pp. 436-442.

9. A. Van der Ziel, "Noise", New York: Prentice-Hall, 1954.

PRACTICAL CONSIDERATIONS IN THE MEASUREMENT OF TRANSDUCER NOISE PERFORMANCE

Presented at the NBS Noise Measurement Seminar
April 30 through May 4, 1984

United States Department of Commerce
National Bureau of Standards
Boulder, CO

by

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I. INTRODUCTION

There are several aspects of transducer (amplifiers, receivers, etc.) noise performance measurements that can introduce errors - some trivial, some significant - into the calculated result. Most of these have been well-publicized in recent years with the introduction of microprocessor based noise figure/noise temperature indicators.

There are however, subtleties associated with the corrections for these effects that could further affect the accuracy of the calculated results. Specifically, this discussion will center on:

- Temperature effects on the noise generator.
- Loss between the noise generator and the unit-under-test (UUT).
- Second-stage noise contributions.

In addition, we will also touch on some practical aspects of the measurement technique in the context of currently applied instrumentation: both analog and the newer digital, microprocessor based instruments.

II. REVIEW OF BASICS

The noise output of a transducer can be described in terms of the defined noise performance factors by means of the rather simple model shown in Figure 1.

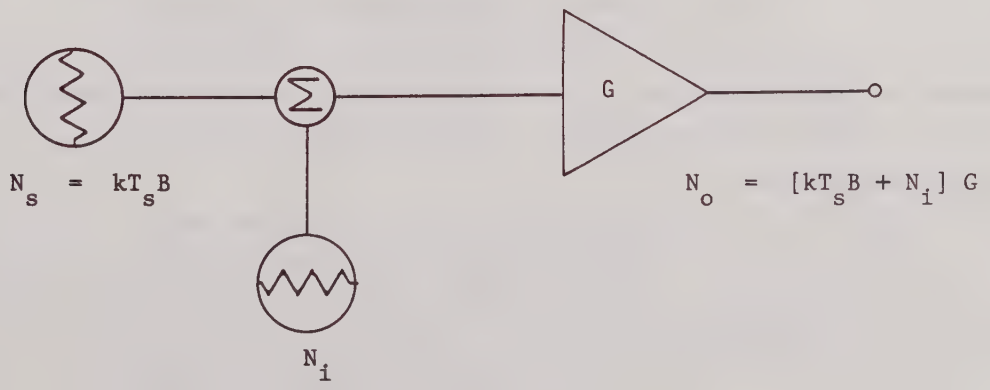


FIGURE 1. THE GENERAL NOISY TRANSDUCER

The noise power available at the output of the transducer is given by:

$$N_o = (kT_sB + N_i)\,G \tag{1}$$

where, N_o = Available noise power at the transducer output
T_s = Source termination temperature
N_i = Noise power generated within the transducer referred to the input
G = Available gain of the transducer

Bypassing the IEEE definitions for the moment, we can describe noise figure as the ratio of the noise power available at the output of the actual transducer to that of an ideal transducer of otherwise identical characteristics when the transducer source termination is at the standard reference temperature, T_o (290 K). Applying this concept:

$$F = \frac{N_{act}}{N_{ideal}} = \frac{(kT_oB + N_i)\,G}{kT_oBG} \tag{2}$$

and,

$$N_i = (F-1)kT_oB \tag{3}$$

Effective input noise temperature can be described as the temperature assigned to a thermal source which represents the internally generated noise of the transducer referred to its input.

$$N_i = kT_eB \tag{4}$$

Referring back to Figure 1, we can write equations for the noise power available at the output of the transducer in terms of either noise figure or effective input noise temperature:

$$N_o = [T_s + (F-1)T_o]kBG \tag{5}$$

or,

$$N_o = (T_s + T_e)kBG \tag{6}$$

Graphically, if N_o versus T_s is plotted, the result is the now familiar straight line representation shown in Figure 2.

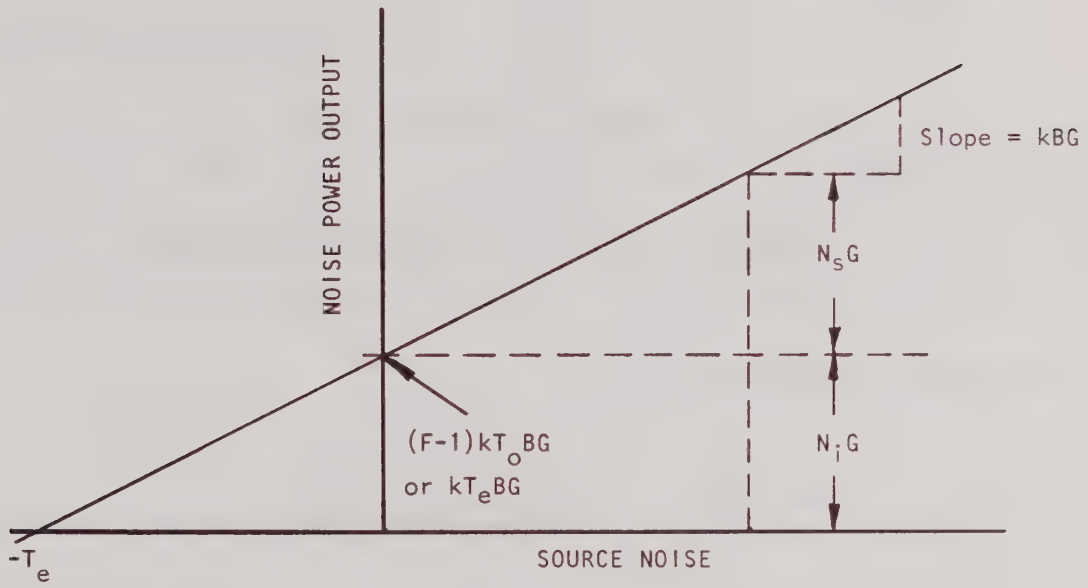


FIGURE 2.
GRAPHICAL REPRESENTATION OF TRANSDUCER NOISE POWER OUTPUT versus SOURCE TERMINATION NOISE

The currently accepted method of determining noise figure or effective input noise temperature is generally referred to as the "Y-factor method". Y-factor is the ratio of the noise powers available at the output of the transducer as the input is switched between two, known source termination temperatures. This is shown schematically in Figure 3.

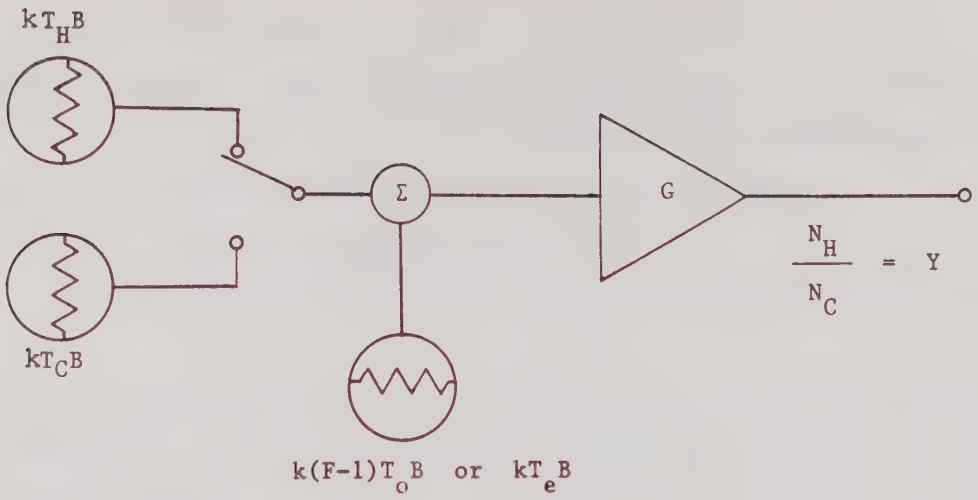


FIGURE 3. SIMPLIFIED MEASUREMENT BLOCK DIAGRAM

From Figure 3 and Equation (5):

$$Y = \frac{N_H}{N_C} = \frac{[T_H + (F-1)T_o]\ GkB}{[T_C + (F-1)T_o]\ GkB} \tag{7}$$

and,

$$F = \frac{R - Y\ \frac{T_C}{T_o} - 1}{Y - 1} \tag{8}$$

where,

$$R = \frac{T_H}{T_o} - 1 \tag{9}$$

The quantity, R, is generally referred to as the excess noise ratio (ENR) of the noise generator and is usually expressed in dB. In earlier literature, before general acceptance of the term, ENR was referred to in a variety of ways including "available excess noise temperature" and "relative excess noise temperature".

Alternatively, (7) could have been written in terms of effective input noise temperature, and:

$$T_e = \frac{T_H - YT_C}{Y - 1} \tag{10}$$

III. ENVIRONMENTAL CONSIDERATIONS

Most people in the technical community involved in noise measurements of amplifiers, etc. are aware of the fact that analog noise figure indicators (and virtually all earlier calculation aids) relied on the assumption that the cold source temperature is equal to the standard reference temperature (290 K) when the cold, or "off", temperature of the noise generator is that of the environment; that is,

$$T_C = T_o \tag{11}$$

If the assumption is valid, then (8) reduces to:

$$F = \frac{R}{Y - 1} \tag{12}$$

The standard reference temperature, however, equates to about 17°C or 62°F. Obviously then, the use of the simplification, (12), usually results in an error in the calculated value of noise figure.

Until the appearance of very low noise devices, the error, for most laboratory situations, was relatively insignificant in comparison to other uncertainties in the measurement configuration (most notably the ENR of the noise generator and, below UHF, mismatch uncertainties). This is illustrated by Figure 4 which plots the error in the measured noise figure versus the measured value for various cold source termination temperatures.

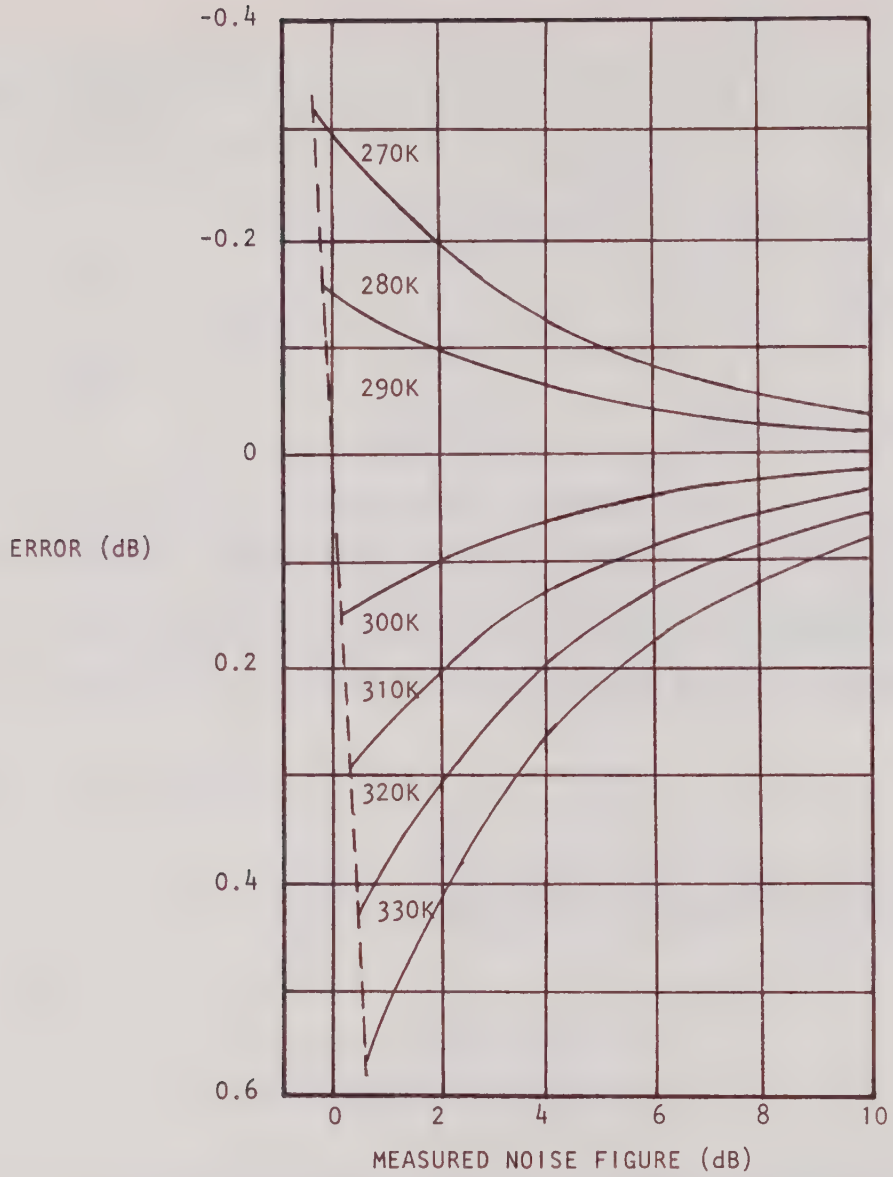


FIGURE 4. ERROR IN MEASURED NOISE FIGURE RESULTING FROM THE ASSUMPTION THAT $T_C = T_o$ (ENR = 15.3 dB)

These curves are plotted for an ENR of 15.3 dB - typical of a commercially available noise generator.

As can be seen from Figure 4, the error is relatively small until the UUT noise figure reaches very low values (<3 dB) and/or the cold source termination temperature is widely removed from 290 K; e.g., if the UUT noise figure is 1.9 dB and T_C is 300 K (about 27°C or 82°F), then the error is only +0.1 dB.

The newer, microprocessor based noise figure indicators effectively eliminate even this small error by incorporating Equation (8) in their firmware, rather than the simplified version, (12), and allowing operator entry of T_C.

Not so well known - or publicized - is that solid state noise generators, the most popular currently applied type, exhibit a hot or "on" temperature gradient with environmental temperature. Virtually all commercially available types are characterized, in terms of ENR gradient, as:

$$<+0.01 \text{ dB/ } ^\circ\text{C}$$

Actual values, determined empirically, range between +0.004 to +0.008 dB/ °C.

As with the cold temperature deviations, the effect is not generally severe since the noise generators are calibrated in relatively closely controlled environments, and the operating temperatures are usually within a few degrees of the calibration temperature.

However, let's look at the untypical case - where there is a large temperature excursion. Table I charts the results of measuring our hypothetical 1.9 dB amplifier using a solid state noise generator with an ENR of 15.3 dB at 296 K as the temperature ranges from 290 to 310 K (about 17° to 37°C). The noise generator is assumed to exhibit the maximum gradient of +0.01 dB/ °C and has been calibrated in a 296 K environment.

TABLE 1

Ambient Temp (K)	ENR (dB)	F_A (dB)	F_B (dB)
290	15.24	1.960	1.960
292	15.26	1.960	1.940
294	15.28	1.960	1.920
296	15.30	1.960	1.900
298	15.32	1.960	1.880
300	15.34	1.960	1.859
302	15.36	1.960	1.838
304	15.38	1.959	1.817
306	15.40	1.959	1.796
308	15.42	1.958	1.775
310	15.44	1.958	1.753

F_A = Uncorrected noise figure using the simplified relation

F_B = Noise figure corrected for $T_C \neq T_o$ only

The column entitled F_A lists the results that would be obtained using the simplified relation, (12); that is, the indication of an analog indicator. F_B lists the results of using the more correct Equation (8). T_C variations are accounted for; however, the user is unaware of the ENR/temperature gradient.

It should be emphasized that the conditions used to generate Table 1 have been deliberately exaggerated to highlight the potential problem: the maximum ENR gradient was used; the temperature range (about 17°C to 37°C) would seldom be encountered in practice. In general, most laboratory measurements would be made in the temperature range bracketed in the table.

IV. LOSS BETWEEN THE NOISE GENERATOR AND THE UNIT

Quite often in practice, it is necessary to interface the noise generator to the UUT input through some component with finite loss; for example, adapters may be necessary to mate the noise generator to the UUT, or an isolator or attenuator may be inserted to reduce mismatch variations seen by the UUT as the noise generator is switched on and off.

The loss of the inserted components changes the source termination temperatures as seen by the UUT. The effect can be analyzed with the aid of the model shown in Figure 5. It consists of a matched system made up of a thermal source, a lossy element with transmission efficiency η, and a load all at the same temperature.

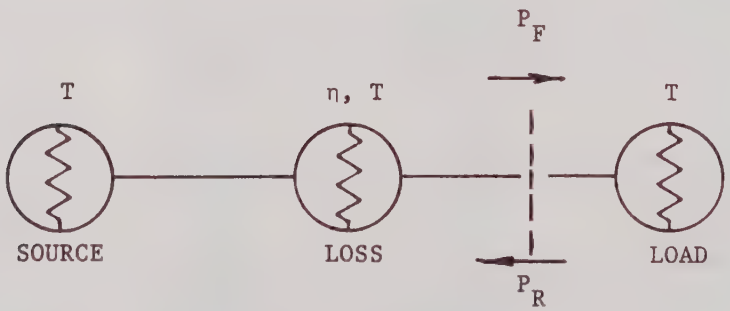


FIGURE 5. MODEL USED TO DETERMINE THE NOISE CONTRIBUTION OF A LOSSY ELEMENT

Since the system is in thermal equilibrium, the second law of thermodynamics requires that the net power flow across the interface between the lossy element and the load be zero; i.e.,

$$P_F = P_R \tag{13}$$

$$N_s + N_\eta = N_L \tag{14}$$

where, N_s is the contribution of the source noise to P_F
N_η is the contribution of the lossy element to P_F
N_L is the noise generated by the load and is equal to P_R.

Then,
$$\eta kT + N_\eta = kT \tag{15}$$

and,
$$N_\eta = (1 - \eta)kT \tag{16}$$

Equation (16) is the noise contribution of the lossy element to the forward power.

This can be extended to a system with arbitrary temperatures in order to determine the effect on applied source temperature and ENR. The symbols are defined in Figure 6.

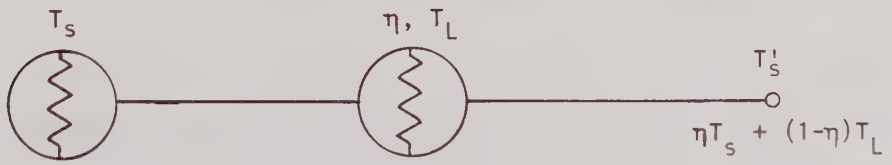


FIGURE 6. MODEL ILLUSTRATING THE EFFECT ON NOISE GENERATOR OUTPUT

From Figure 6 and Equation (15),

$$kT_s' = \eta kT_s + N_\eta \tag{17}$$

and from (16),

$$T_s' = \eta T_s + (1 - \eta)T_L \tag{18}$$

The effective ENR, then, is given by,

$$R' = \frac{T_s'}{T_o} - 1 \tag{19}$$

and,

$$R' = \frac{\eta T_s + (1 - \eta)T_L}{T_o} - 1 \tag{20}$$

Quite often, as with cold source temperature, the assumption is made that,

$$T_L = T_o \tag{21}$$

Then,

$$R' = \eta R \tag{22}$$

where,

$$R = \frac{T_s}{T_o} - 1 \tag{23}$$

Equation (22) points out a very common practice which can lead to an additional measurement error; that is, the ENR used for a noise figure calculation is expressed simply as the ENR of the source reduced by the loss. Expressed in dB:

$$R'_{dB} = R_{dB} - Loss_{dB} \tag{24}$$

Again, the error is relatively small except in very critical applications, or where the loss and/or temperature deviation from T_o is large. This is illustrated by Figure 7.

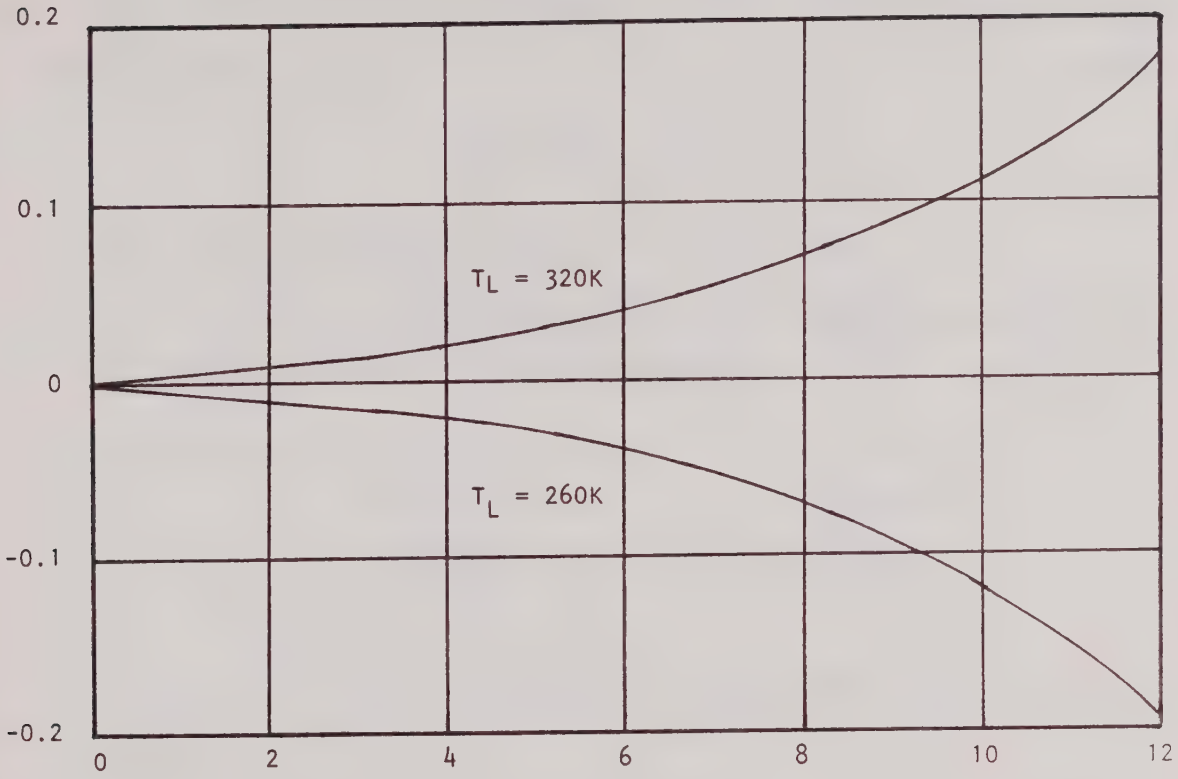


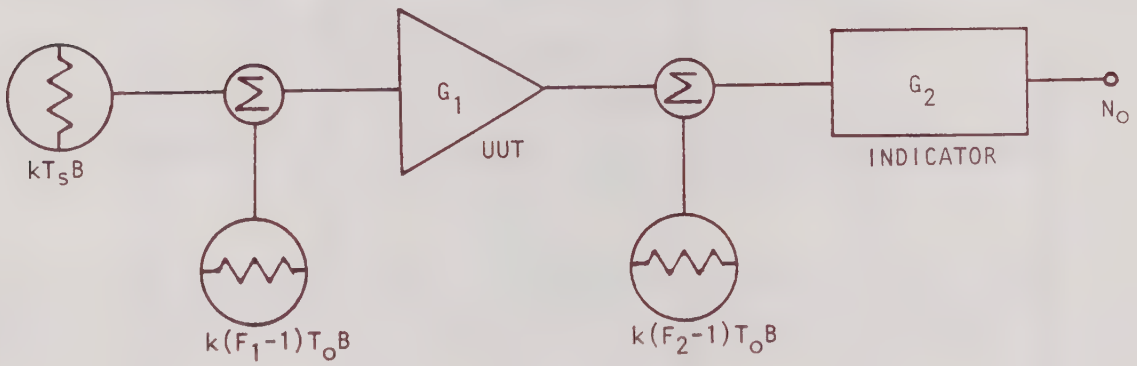
FIGURE 7. DEVIATION OF ACTUAL ENR FROM (ENR_{dB} - $LOSS_{dB}$) vs. LOSS SHOWING THE EFFECT OF LOSS TEMPERATURE

V. SECOND-STAGE NOISE CONTRIBUTION

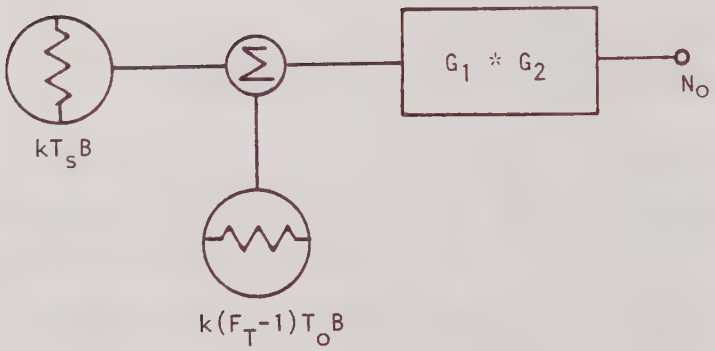
A typical amplifier noise measurement setup consists of a noise generator at the input of the UUT and some type of indicator at it's output. The indicator is, in general, a receiver which, having its own noise characteristics, will contribute to the measured noise performance.

We now have the familiar problem of separating the indicator noise contribution from the measured value in order to determine the noise performance of the UUT alone.

Figure 8 illustrates the classic method of deriving an expression for UUT noise figure in terms of measured overall and second stage values. The noise output powers of the two models, one based on individual contributions, the other on an overall equivalent, are equated. From this the required expression can be derived.



A. MODEL SHOWING INDIVIDUAL NOISE CONTRIBUTORS



B. OVERALL EQUIVALENT

FIGURE 8. MODELS USED TO DERIVE UUT AND INDICATOR NOISE FIGURE FORM OVERALL MEASURED NOISE FIGURE

From Figure 8A:

$$N_o = G_2 \left\{ k(F_2 - 1)T_oB + G_1 [k(F_1 - 1)T_oB + kT_sB] \right\} \quad (25)$$

and from Figure 8B:

$$N_o = G_1G_2 [k(F_T - 1)T_oB + kT_sB] \quad (26)$$

where, F_T is the overall noise figure of the cascade
F_1 and G_1 are the noise figure and gain, respectively, of the UUT
F_2 and G_2 are the noise figure and gain, respectively, of the indicator
T_s is the source termination temperature.

Equating (25) and (26), and solving for F_1:

$$F_1 = F_T - \frac{F_2 - 1}{G_1} \quad (27)$$

Alternatively, if noise performance is expressed as effective input noise temperature:

$$T_{e_1} = T_{e_T} - \frac{T_{e_2}}{G_1} \quad (28)$$

One problem that arises with the use of (27) or (28) is that many people do not recognize the fact that the derivation assumes that the bandwidth of the second stage (the indicator in the illustration) is <u>equal to or less than</u> that of the UUT. If, however,

$$B_1 < B_2 \quad (29)$$

and the bandwidths are carried through the derivation, then (27) and (28) become:

$$F_1 = F_T - \frac{F_2 - 1}{G_1} \left[\frac{B_2}{B_1} \right] \quad (30)$$

and,

$$T_{e_1} = T_{e_T} - \frac{T_{e_2}}{G_1}\left[\frac{B_2}{B_1}\right] \tag{31}$$

The necessity to make this correction is a function of the relative magnitudes of the first and second stage noise performance factors, first stage gain, and the bandwidth ratio. As a general rule-of-thumb, if,

$$G_1 > 100\left[\frac{B_2}{B_1}\right] \tag{32}$$

the correction is trivial.

One way to avoid this correction is to precede the second stage with a narrow band filter insuring that,

$$B_2 < B_1 \tag{33}$$

Barring this practical expedient, it becomes necessary to measure the noise bandwidths in order to determine the correction, and this is not a simple taks.

Noise bandwidth is defined mathematically as,

$$B_N = \int_0^\infty \frac{G(f)df}{G_o} \tag{34}$$

where G_o is the power gain at some reference frequency - usually at the passband peak. Graphically, (34) is represented as shown in Figure 9.

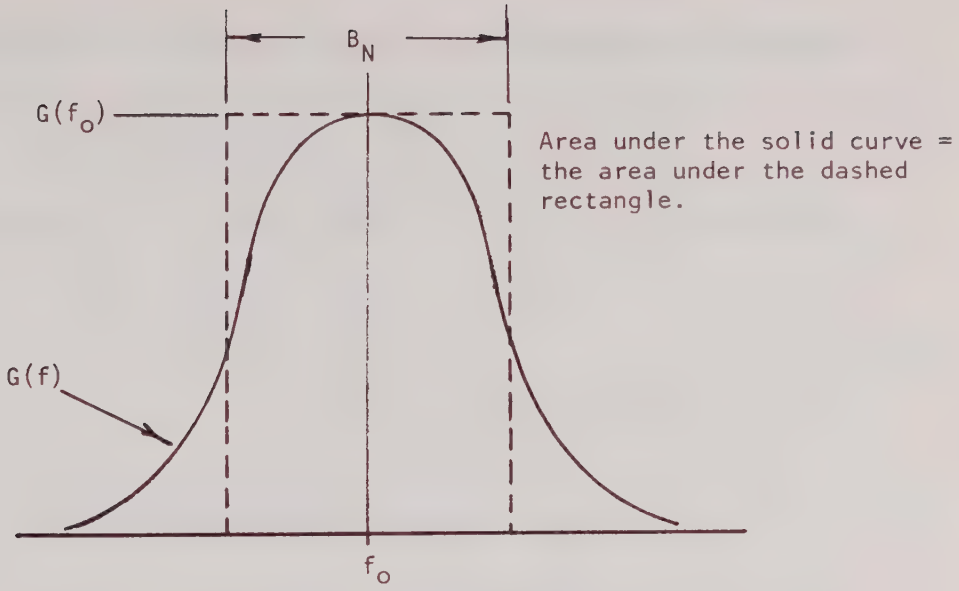


FIGURE 9. ILLUSTRATION OF NOISE BANDWIDTH

Except in the case of multi-stage transducers with steep, well-defined skirts, the noise bandwidth is generally considerably different from the 3 dB bandwidth.

The brute force method of determining B_N would be to make a plot of the transducer's power gain versus frequency curve, measure the area under the curve and calculate the width of the rectangle described in Figure 9.

An experimental method of estimating B_N is illustrated in Figure 10.

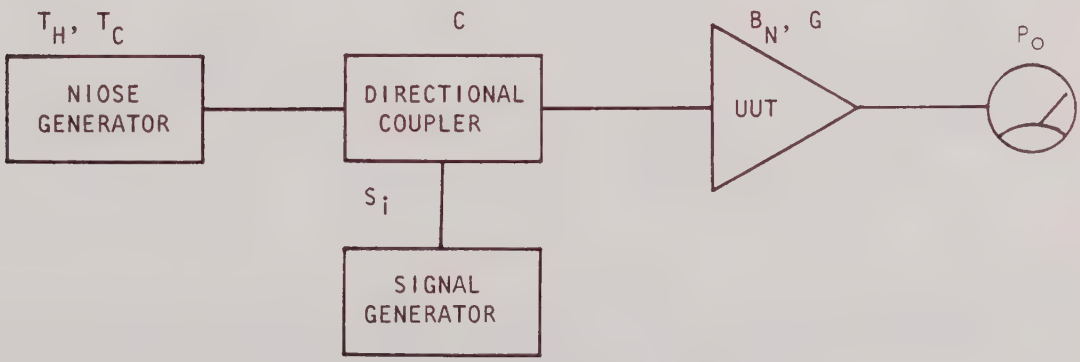


FIGURE 10. SETUP FOR ESTIMATING B_N

With the noise generator on and the signal generator off note P_o.

$$P_o = GB_N k (T_H + T_e) \tag{35}$$

With the noise generator off, adjust S_i until the output again equals P_o.

$$P_o = GCS_i + GB_N k(T_C + T_e) \tag{35}$$

Equate (35) and (36), and solve for B_N

$$B_N = \frac{CS_i}{k(T_H - T_C)} \tag{37}$$

Another potential complication in the use of (27), the standard cascade noise figure equation, arises when the UUT is a broadband amplifier, and the input of the second stage is a mixer with no image rejection and signal enhancement. The situation is illustrated by Figure 11.

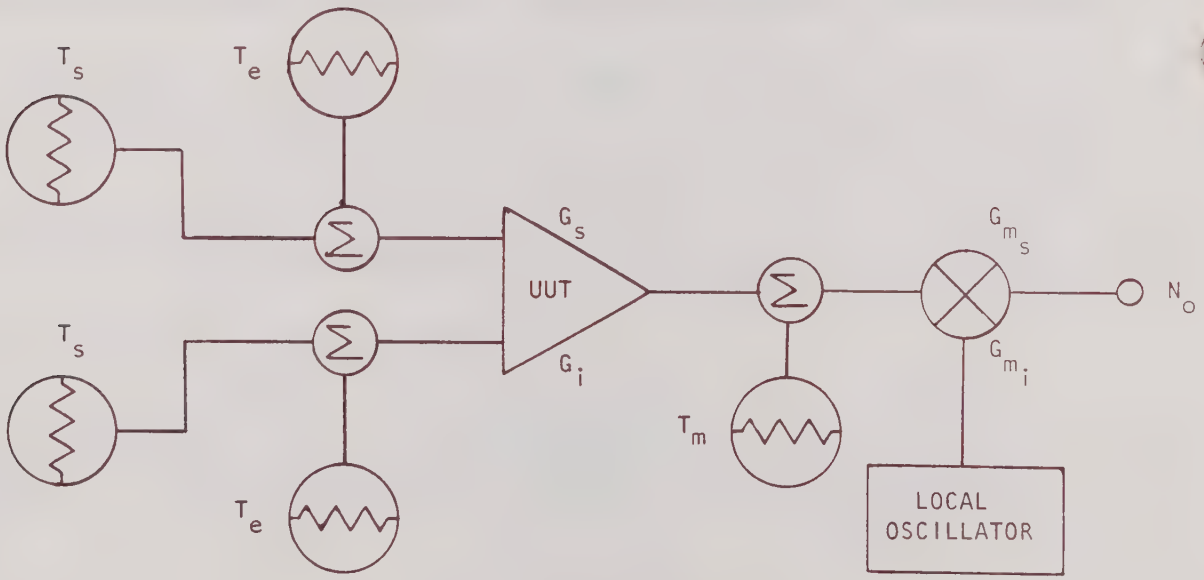


FIGURE 10. HETERODYNE MEASUREMENT MODEL

Here, both noise sidebands are permitted through to the output.

We can write an expression for the measured Y-factor, and derive a cascade noise figure equation for this particular configuration. For simplicity, it will be assumed that the cold source temperature is at T_o (290 K), and the conversion losses of the mixer at the image and signal frequencies are equal; that is,

$$T_C = T_o \tag{38}$$

$$G_{M_i} = G_{M_s} = G_M \tag{39}$$

$$Y = \frac{G_M [2T_M + G_s(T_H + T_e) + G_i(T_H + T_e)]}{G_M [2T_M + G_s(T_o + T_e) + G_i(T_o + T_e)]} \tag{40}$$

$$Y - 1 = \frac{(G_s + G_i)(T_H - T_o)}{2T_M + (G_s + G_i)(T_e + T_o)} \tag{41}$$

Since,

$$\frac{T_H}{T_o} - 1 = R \tag{42}$$

and,

$$\frac{T_e}{T_o} + 1 = F_1 \tag{43}$$

then,

$$Y - 1 = \frac{R}{\frac{2T_m / T_o}{G_s + G_i} + F_1} \tag{44}$$

Given the condition (38), the total or measured noise figure is calculated from:

$$F_T = \frac{R}{Y - 1} \tag{45}$$

Combining (44) and (45),

$$F_T = F_1 + \frac{2T_M / T_o}{G_s + G_i} \tag{46}$$

Since,

$$\frac{T_M}{T_o} + 1 = F_{Md} \tag{47}$$

where F_{Md} is the double sideband noise figure of the mixer (uncorrected for image response),

then,

$$F_1 = F_T + \frac{2(F_{Md} - 1)}{G_s + G_i} \tag{48}$$

If,

$$G_s = G_i = G_1 \tag{49}$$

then,

$$F_1 = F_T + \frac{F_{Md} - 1}{G_1} \tag{50}$$

The form of (50) is the same as the standard cascade relation, (27); however, the user should be aware of the conditions - the second stage noise figure should not be doubled to account for the image response [note, from (48) that the second stage contribution is doubled], and the image and signal frequency gains are equal.

The latter condition is not difficult to achieve in practice where this measurement configuration is normally used; that is, at microwave frequencies using a low intermediate frequency so that the separation between image and signal frequencies is small compared to the local oscillator frequency, and the gains are essentially equal.

VI. OTHER PRACTICAL CONSIDERATIONS

The topics in this section are, for the most part, obvious and can be classified as application of good measurement technique; however, they are quite often ignored for some reason - sometimes with disastrous results. It is estimated that at least half of the reported noise measurement problems are solved by application of one or more of the considerations discussed here.

Connectors

Much has been said in recent years about the care and feeding of the modern microwave connector particularly with regard to noise measurements, and with good justification.

Today's RF and microwave low noise amplifiers use SMA or similar compatible connectors almost exclusively; consequently, noise instrument manufacturers have followed simply to make their offerings more palatable to the marketplace. The physical size alone makes these connectors more susceptible to wear and damage than, say, a precision, stainless steel Type N.

It is important to note that the integrity of a noise generator output connector has a direct bearing on the accuracy and precision of the ENR calibration. If it is worn or damaged, it must be replaced, and the noise generator must be recalibrated.

Some guidelines for connectors are:

1) Always visually inspect both the noise generator output and UUT input connectors for foreign material before mating.

   Clean if necessary.

2) Periodically swab the connector internal surfaces. Some inadvertent abrasion of internal surfaces is almost unavoidable. Allowing dirt and minute metallic particles to collect will eventually destroy the connectors.

3) Don't overtighten! Use a torque wrench. This is a good practice anyway to insure measurement repeatability.

4) Carefully align the connectors before rotating the coupling nut. Do not turn the entire body of the noise generator to tighten the connection.

EMI

Noise figure indicators are sensitive receivers. Inserting an amplifier ahead of the indicator increases that sensitivity - and the susceptibility of the measurement system to interference from even relatively small external signals.

Commercially available noise figure indicators are generally well-shielded against external interference; however, that shielding effectiveness must be carried over to the external components and connections. Interfering signals will cause erratic and artificially high readings.

In many instances it is necessary to make measurements on an unshielded amplifier (for alignment or noise optimization). In these cases it is almost always necessary to move the measurement setup into a shielded room to prevent interference from external signals.

Use double-shielded or semi-rigid cable where possible. Single braid cable generally will not provide sufficient shielding even in a moderate electromagnetic field environment. If at all possible, do not use BNC connectors. The shielding effectiveness is poor, and the connections become erratic after moderate usage.

Radiated emissions are not the only problem. Measurements at microwave frequencies require a mixer and local oscillator external to the indicator. Spurious signals within the passband of the indicator generated by the local oscillator could feed through to the mixer IF port and will cause the same problems as radiated interference (local oscillator selection will be discussed in more detail later).

UUT Linearity

In order to accurately measure the noise performance of a receiver, the receiver must be linear over the full excursion of the Y-factor - and beyond.

A common misconception is that since we are working with noise, the levels are too small to activate a receiver's automatic gain control (AGC) circuits; however, AGC is enabled in many receivers (high sensitivity telemetry receivers, TV receivers, etc.) just a few dB above the internal noise level. When the noise generator is turned on (hot), AGC action will reduce the gain and the indicted noise figure will be higher than expected.

In these cases, it is necessary to disable the AGC, and then insure that the UUT remains linear to about 20 dB above the average noise power level. The signals in this measurement are random noise, and clipping of the noise "spikes" will result in a pessimistic indication.

Local Oscillator Selection

Selection of the external local oscillator for microwave measurements will have a bearing measurement accuracy. L.O. noise downconverted to the IF will become part of the second stage noise contribution and, in some instances, raise the second stage noise beyond the measurement range of current instrumentation.

The variation of the cascade noise figure equation, (27), used to extract UUT noise figure from the overall measured result is repeated here for reference.

$$F_1 = F_T - \frac{F_2 - 1}{G_1} \tag{51}$$

Intuitively, we know that if F_T and the second term of (51) are large and near in magnitude, then the accuracy of F_1 suffers.

This can be further illustrated by writing an expression for the uncertainty in F_1 as a function of the uncertainties in the three measured quantities.

$$\Delta F_1 = \left|\frac{\partial F_1}{\partial F_T}\right| \Delta F_T + \left|\frac{\partial F_1}{\partial F_2}\right| \Delta F_2 + \left|\frac{\partial F_1}{\partial G_1}\right| \Delta G_1 \qquad (52)$$

Noting that in general,

$$\Delta A_{dB} = 4.34 \frac{\Delta A}{A} \qquad (53)$$

and taking the indicated derivatives, then:

$$\Delta F_{1_{dB}} = \frac{F_T}{F_1} \Delta F_{T_{dB}} + \frac{F_2}{F_1 G_1} \Delta F_{2_{dB}} + \frac{(F_2 - 1)}{F_1 G_1} \Delta G_{1_{dB}} \qquad (54)$$

Since F_T contains F_2, then each uncertainty contribution incorporates second stage noise figure as a multiplier, verifying intuition.

While not impossible, it is difficult to quantify those characteristics of a signal source that make it suitable or not as a local oscillator in a noise measurement application; however, some general guidelines can be stated, and an approximate analysis will be offered later.

As noted earlier, spurious signals in the passband of the indicator or those that could be downconverted to the IF cannot be tolerated. Mixer L.O. drive levels of +10 dBm are not uncommon. Even with spurious performance 80 dB below the carrier (-80 dBc), the spurious level at the mixer would be -70 dBm. This could easily be 20 to 30 dB greater than the noise signals we are trying to measure.

This tends to rule out signal sources using heterodyne techniques which includes several commercial sweepers and synthesizers.

Since noise performance is a relatively wideband measurement, noise close to the carrier is not important as long as it is not grossly poor; consequently, frequency stabilized sources are not a necessity.

L.O. noise that is converted into the IF passband is important. This is quite far removed from the L.O. center frequency (10 MHz or more) and is generally referred to as "floor noise".

The floor noise of signal sources employing phase-locked loops (at the output), tunable cavities, and tracking output filters is generally two to three orders of magnitude better than those with broadband amplifiers in the output section due to filtering effects.

The impact of L.O. noise can be estimated in the following way. Assume the following conditions:

L.O. Noise floor:	-120 dBc/Hz
Measurement bandwidth:	5 MHz
L.O. - IF noise isolation:	20 dB
L.O. level:	+10 dBm

From these considerations we can determine that the L.O. noise at the IF input port is about -63 dBm or 500×10^{-9} mW.

Let's further assume that the measured noise figure of a setup similar to that shown in Figure 10 using a "clean" or noiseless L.O. is 2 dB, the gain of the UUT is 20 dB, and the mixer conversion loss is 7 dB. If the UUT source termination is at 290 K, then, from (5)

$$N_o = FkT_oBG_N \tag{55}$$

and the noise level at the IF port is about -92 dBm or 0.6×10^{-9} mW - almost three orders of magnitude less than the L.O. noise.

Obviously, this source is unacceptable. It would be preferable to have the floor noise in the same order of magnitude as the mixer/IF amplifier noise level.

VII. CONCLUSIONS

The major correctable errors in amplifier noise measurements are well known; however, in some instances, under certain specific conditions, these corrections have to be applied with knowledge and care to avoid exaggerating, rather than correcting the errors. A degree of familiarity with the basics of noise measurement theory will help avoid these complications.

There are several practical aspects to amplifier noise measurements which are seemingly obvious applications of logic and common sense; however, quite often these are ignored in the interests of haste, economics, manpower loading, etc. When this happens, there is the potential for a great deal of economic waste in terms of damaged instruments with attendant repair and recalibration costs, time loss due to the necessity to repeat measurements, and rework of "failed" devices that were actually within performance limits, or worse - the converse which could cause a system to perform below minimum requirements.

- Smoothing the 2075 Display
- Microwave Noise Measurements with the 2075
- Microwave Noise Figure Measurements with the 2075 Using The Swept L.O. Mode
- Creating a User-Defined Local Oscillator Program

SMOOTHING THE 2075 DISPLAY

Measurement of noise figure or other noise parameters involves taking the ratio of the two noise levels at the output of the Unit-Under-Test (UUT) when a noise source connected to the UUT is keyed on and off.

Since these two signals are truly random in nature, it is to be expected that the output display will "jitter" - vary randomly. The range of these fluctuations can be described, generally, bay application of radiometric principles (noise measuring instruments, as a class, are some form of radiometer).

$$\overline{\overline{\quad}} = f[T_s, F, (B\mathcal{J})^{-\frac{1}{2}}]$$

where, $\overline{\overline{\quad}}$ represents the RMS amplitude of the fluctuations.

B is the bandwidth of the measuring system prior to detection (usually the IF bandwidth of the measuring system).

$\mathcal{J}$ is the post detection time constant.

T_s is the source termination temperature.

F is the noise figure (or temperature).

In analog instruments and earlier digital units (7360/70, 7380), B and $\mathcal{J}$ are fixed. $\mathcal{J}$ usually is set by the integrating or smoothing capacitor across the meter terminals. The IF bandwidth of noise instruments is selected as a compromise to cover a number measurement situations based on other factors, and is fixed.

Thus, the only way to reduce the range of the random fluctuations - "smooth" the display - is to increase the post detection time constant. Increasing the time constant reduces the random jitter in the output display in both amplitude and perceived frequency.

Smoothing the output display, however, has a related effect: as the post detection time constant is increased, the response time of the measuring system also

increases. In other words, an instrument with a heavily integrated (smoothed) output display will be slow to respond to changes in the measured noise parameter.

As with IF bandwidth, the smoothing (post detection time constant) in analog instruments was selected as a compromise between response time and display (meter) jitter for a "nominal" measurement situation.

Optimum smoothing however, will be different for various measurement situations. For example:

- A long response time (heavy smoothing) can be tolerated for a single frequency, precision measurement.

- Heavy smoothing is desirable for a single frequency noise stability check versus time.

- Less smoothing - faster response - is desirable for swept measurements to increase measurement speed (reduce the time required for a complete sweep) especially when the results are displayed on a low resolution output device such as an oscilloscope or X-Y recorder.

- Faster response is also desirable when a Unit-Under-Test is being adjusted for optimum noise performance so that the effect of the adjustments can be observed virtually as they occur.

- Heavier smoothing is necessary for high resolution measurements as the noise figure or temperature increases.

The 2075 solves this apparent dilemma through its highly digitally oriented design. Display smoothing or integration is accomplished by the simple expedient of taking the average of a number of measurements. Increasing or decreasing the number of measurements averaged increases or decreases the smoothing.

In order to reduce jitter in the displayed date (D) derived from the measured data (M), a smoothing function with a variable smoothing factor (S_F) is applied to the measured data. The smoothing factor is variable from 1 to 512, and is selectable either from the front panel or via the IEEE-STD-488 interface bus (GPIB).

A front panel segmented light bar display provides an indication of smoothing selected. The ten segments represent the smoothing number. The relationship between smoothing number (S_N) which ranges from 1 to 10 and smoothing factor is given by:

$$S_F = 2^{(S_N - 1)}$$

The general measurement cycle is illustrated in simplified form by the following flow chart. The noise generator is turned on and off, and the two noise signals are measured. The desired measurement parameter (noise figure, effective input noise temperature, etc.) is calculated using previously input parameters (ENR, cold reference temperature, frequency). The smoothing function is applied and the results are displayed. The cycle then begins again.

The smoothing function algorithm is designed to assign greater and greater weight to prior measurements as the smoothing number (or smoothing factor) is increased. The exception to this statement is the first measurement in a new or start-up configuration. In this case, the measured data is displayed with smoothing.

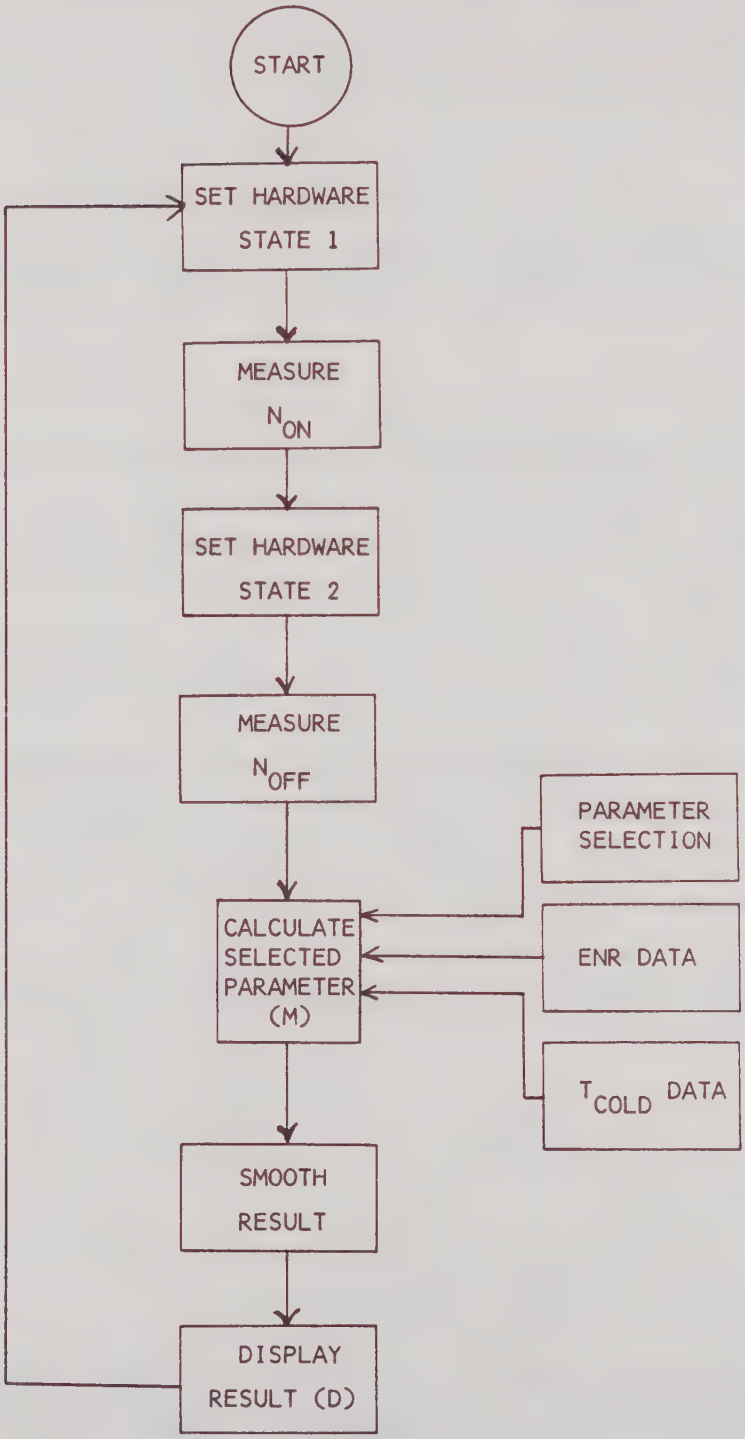
The smoothing algorithm can be described mathematically as follows:

$$D_{(n)} = \frac{D_{(n-1)} [S_F - 1] + M_{(n)}}{S_F}$$

The subscript, (n), refers to the current measurement cycle, while (n-1) refers to the immediately preceding measurement cycle.

If the smoothing number, S_n, selected by the user is in unity ($S_F = 1$), then there is no smoothing. The displayed data is equal to the measured data for each measurement cycle.

GENERAL MEASUREMENT CYCLE



The flow chart following details application of the smoothing algorithm; however, probably of more interest is the table below which shows the displayed data for a series of measurement cycles in which the measured data jitters normally for five measurement cycles, then shifts to a relatively constant value for the remaining cycles. The displayed data is shown for several different smoothing numbers. The effect is further illustrated by the graph of displayed data versus measurement cycle.

n	$M_{(n)}$	DISPLAYED DATA				
		1	2	3	4	8
		2	4	8	8	128
1	2.52	2.52	2.52	2.52	2.52	2.52
2	2.48	2.48	2.50	2.51	2.52	2.52
3	2.56	2.56	2.53	2.52	2.52	2.52
4	2.53	2.53	2.53	2.52	2.52	2.52
5	2.49	2.49	2.51	2.52	2.52	2.52
6	2.45	2.45	2.48	2.50	2.51	2.52
7	2.44	2.44	2.46	2.48	2.50	2.52
8	2.45	2.45	2.46	2.48	2.49	2.52
9	2.45	2.45	2.45	2.47	2.49	2.52
10	2.44	2.44	2.45	2.46	2.48	2.52

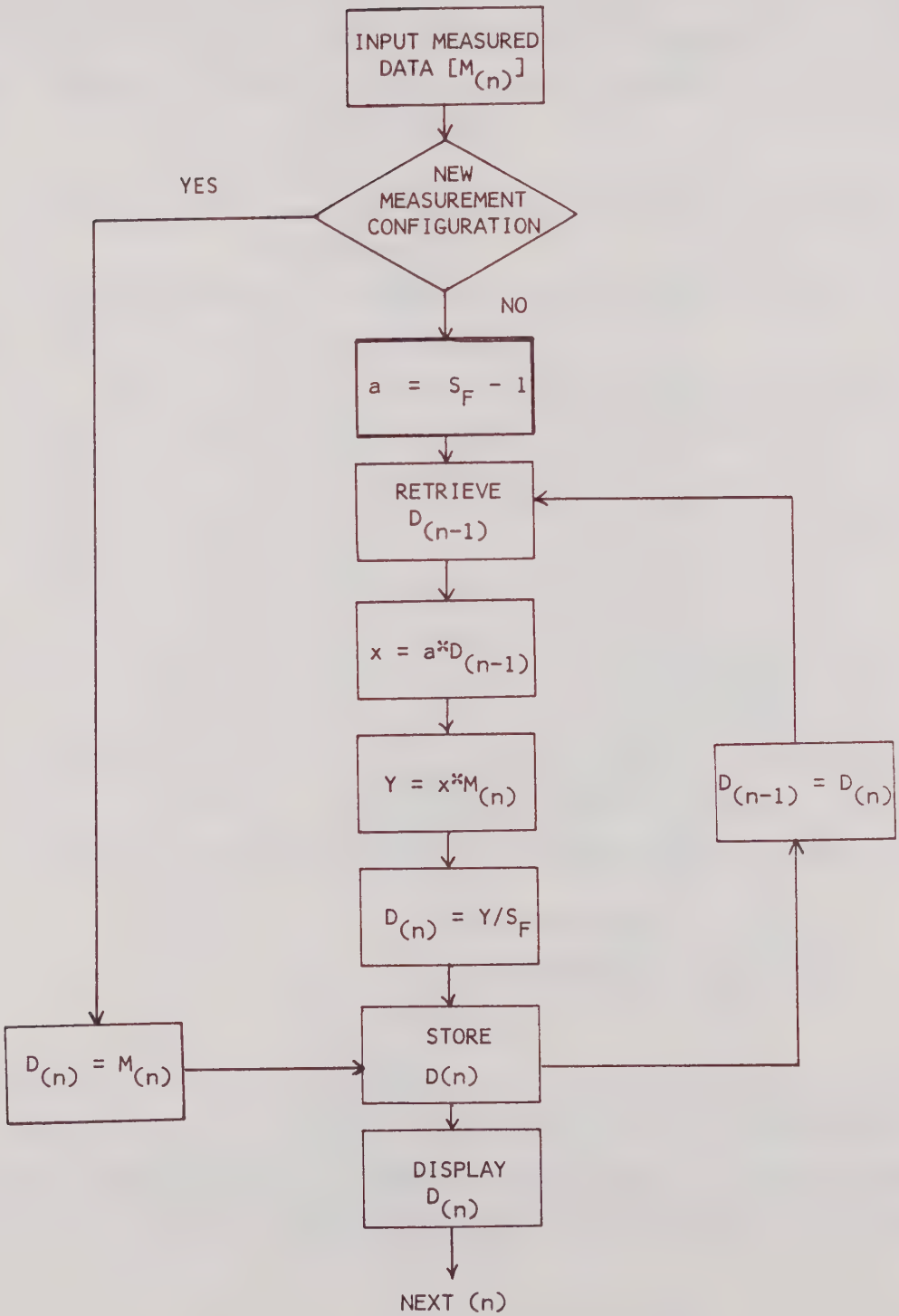
Smoothing Number
Smoothing Factor

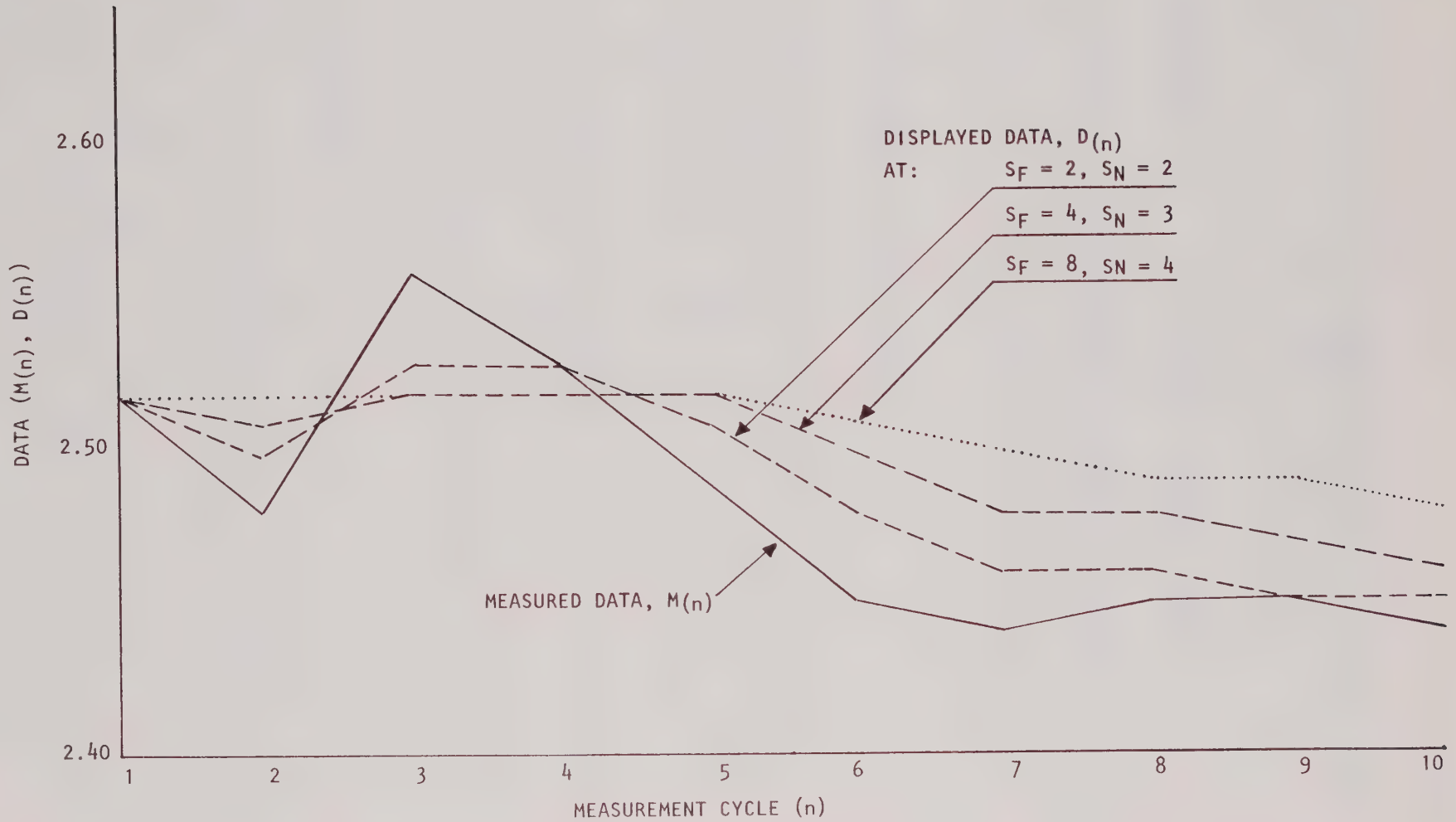
n = measurement cycle

$M_{(n)}$ = measured data

As can be seen from the data, a higher smoothing number reduces the jitter, but it also increase the time required for the display to react to a change. With a smoothing number of 8, ten additional measurements would be required at the lower value of noise figure before the displayed data would be reduced by 0.01 dB.

SMOOTHING FUNCTION




DISPLAYED DATA, D(n)
AT: SF = 2, SN = 2
SF = 4, SN = 3
SF = 8, SN = 4
MEASURED DATA, M(n)
DATA (M(n), D(n))
2.60
2.50
2.40
1
2
3
4
5
6
7
8
9
10
MEASUREMENT CYCLE (n)

What is important is that the 2075 offers the user a choice:

- Low smoothing and fast response for "quick look" measurement.
- Interim values of smoothing with reasonable response times for most normal measurement situations.
- Heavy smoothing for obersation of long term trends.

TECHNICAL BULLETIN

2075 NOISE GAIN ANALYZER

MICROWAVE MEASUREMENTS ABOVE 1.8 GHz

I. INTRODUCTION

This bulletin is intended to be an introduction to the microwave measurement capabilities of the 2075 Noise Gain Analyzer. It will provide an overview of the various measurement configurations available and describes an operational example of one of these configurations.

II. DEVICE UNDER TEST (DUT) CONFIGURATION

All operating parameters of the measurement, such as ENR selection, sideband selection, operating frequencies, etc., are programmed for entry by the 2075 firmware upon selection of a DUT configuration mode. Failure of the operator to enter a required parameter will result in an error message or selection of a default parameter by the 2075.

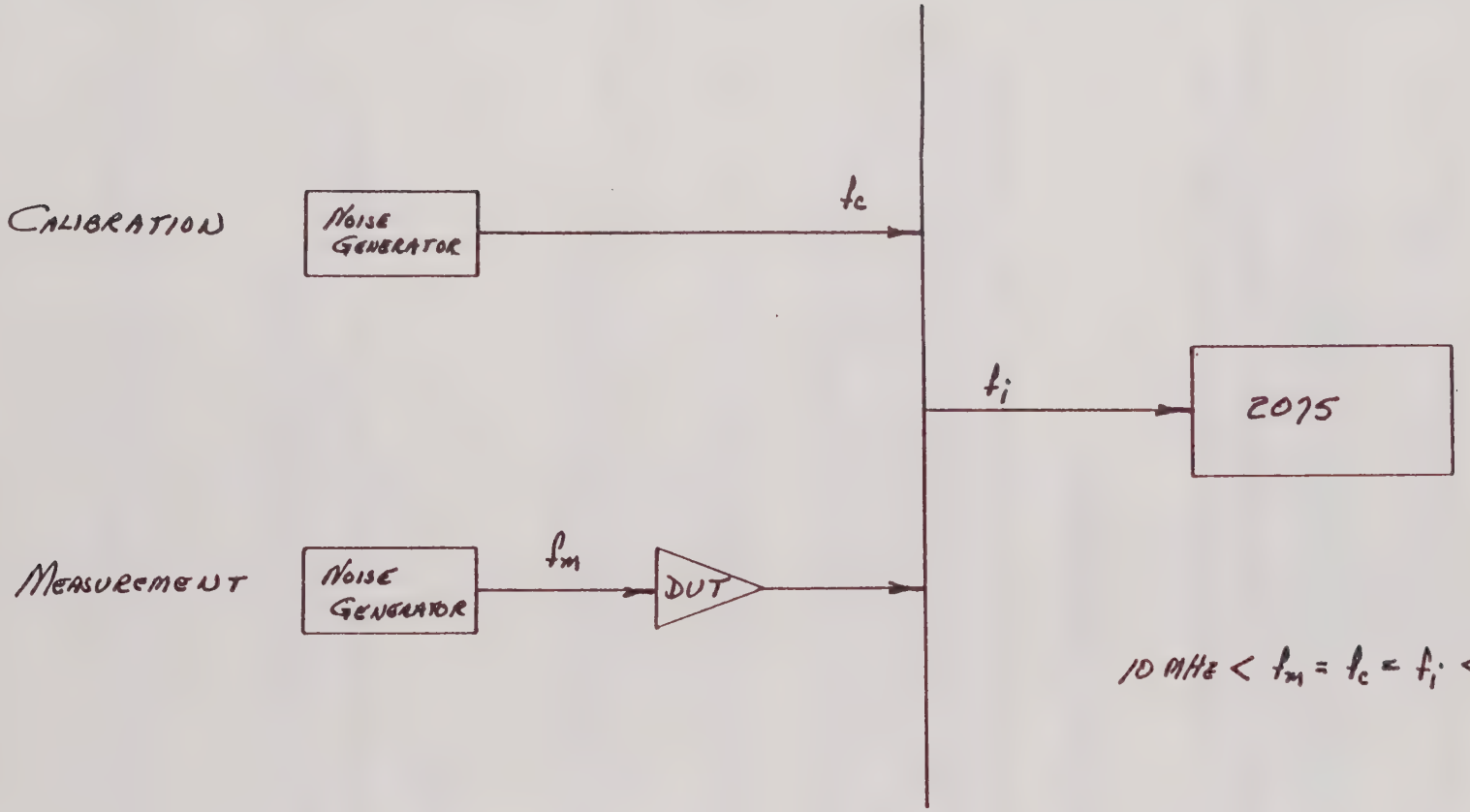
The error message codes are interpreted by the instruction manual and prompt entry of the required parameters.

The following diagrams and descriptions detail the various configuration modes and typical applications available in the 2075.

Configuration 1.1

This is the default configuration if no other is selected via the special functions. It is also the simplest as it applies to the measurement of an amplifier operating within the 10 to 1800 MHz frequency range.

As shown by the following diagram, the key condition of this mode is that the calibration, measurement, and 2075 input frequencies are identical.



$10\ MHz < f_m = f_c = f_i < 1800\ MHz$

DUT CONFIGURATION 1.1

In this mode, image corrections are not necessary as it is a true single sideband measurement. The low pass filter ($f_c \approx 1900$ MHz) at the 2075 input and the upconversion scheme effectively removes the image.

Configuration 1.2

This is one of the two configurations available in the 2075 for measurement of microwave amplifiers operating above 1800 MHz. It is generally referred to as the "swept L.O., fixed I.F." mode, and requires a GPIB controllable signal source of a type whose programming format is stored in the 2075 firmware, or one whose programming requirements fit the general format available in the 2075. The signal sources preprogrammed into the 2075 are:

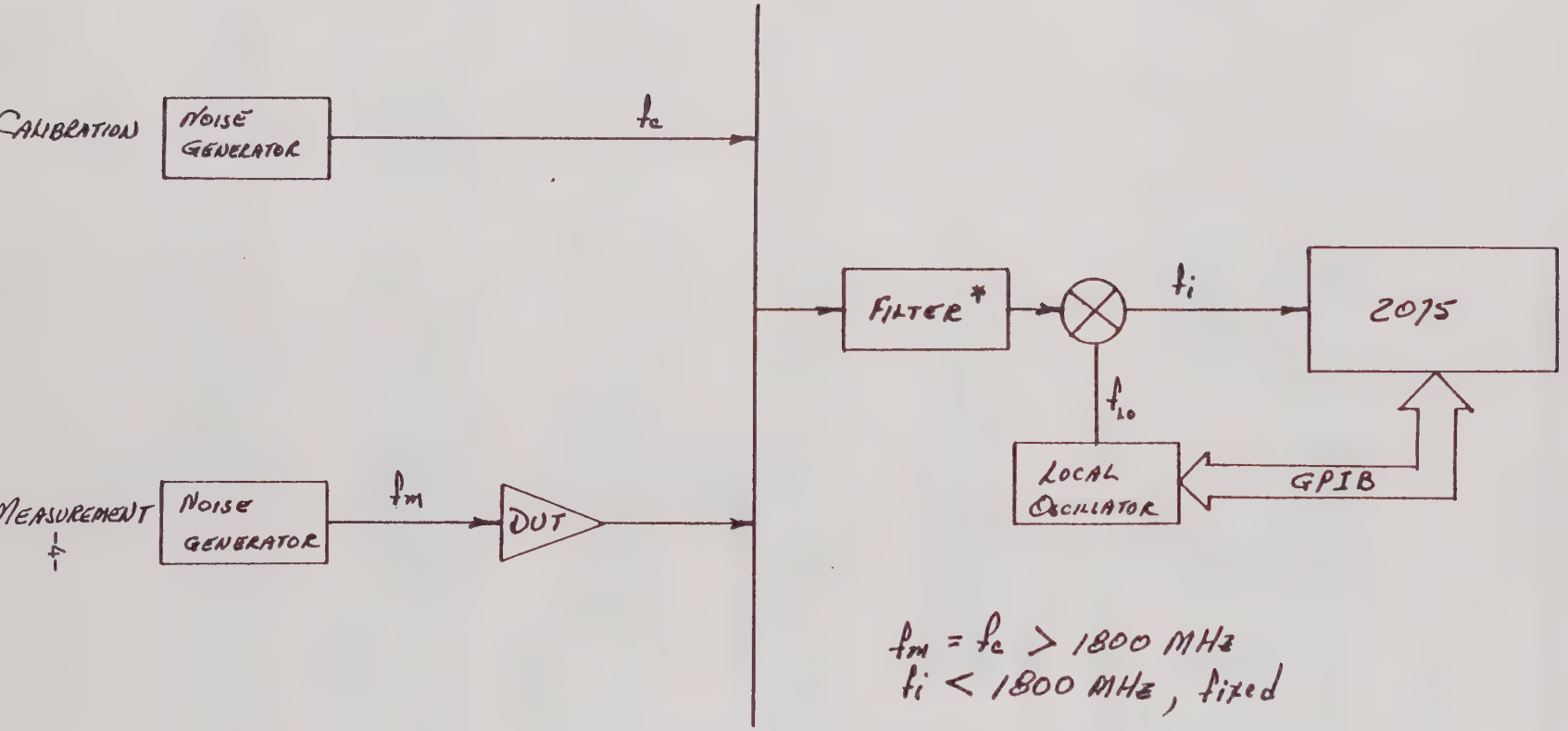
Wiltron 6647A
Hewlett-Packard 8350A
Hewlett-Packard 8672A
Giga

This configuration mode offers the operator the option of single or double sideband measurements. The single sideband measurement can be either upper or lower sideband.

As shown in the block diagram, the key conditions of this mode are that the calibration and measurement frequencies are identical, but they are greater than 1.8 GHz and differ from the 2075 input frequency which is less than 1.8 GHz.

Double sideband measurements would generally be made on very broadband amplifiers: e.g., an ECM amplifier operating from 6 to 18 GHz. Unless a tracking preselector follows the DUT, there is no way the 2075 can eliminate the image.

Single sideband measurements can be made with a minimum of complications on amplifiers with relatively small passbands (BW < 1800 MHz) such as a satellite receiver LNA operating from 3.7 to 4.2 GHz.



$f_m = f_c > 1800$ MHz
$f_i < 1800$ MHz, fixed

* DELETE FOR DOUBLE SIDEBAND MEASUREMENTS
OPTIONAL FOR SINGLE SIDEBAND MEASUREMENTS
(SEE TEXT)

DUT CONFIGURATION 1.2

The filter shown in the diagram may be required for single sideband measurements. Amplifiers designed for a specific system (satcom, radar, telemetry, etc) will usually have well-defined passbands with gains at the image frequencies generally more than 20 dB below the gains within the amplifier passband. The filter is unnecessary in these cases.

If the amplifier does have significant gain at the image frequencies relative to the passband gain, the filter is required for single sideband operation; however, as will be shown, the filter characteristics are not critical.

As an illustration, suppose we wished to measure an amplifier over the range from 5.9 to 6.5 GHz. We could select lower sideband operation with an I.F. of 1.8 GHz (L.O. sweeps from 7.7 to 8.3 GHz). The image frequency range is 9.5 to 10.1 GHz; thus, the filter cutoff frequency can be anywhere from just above 6.5 GHz to less than 9.5 GHz. The only requirement being that the rejection above 9.5 GHz be about 20 dB or more below the passband transmittance.

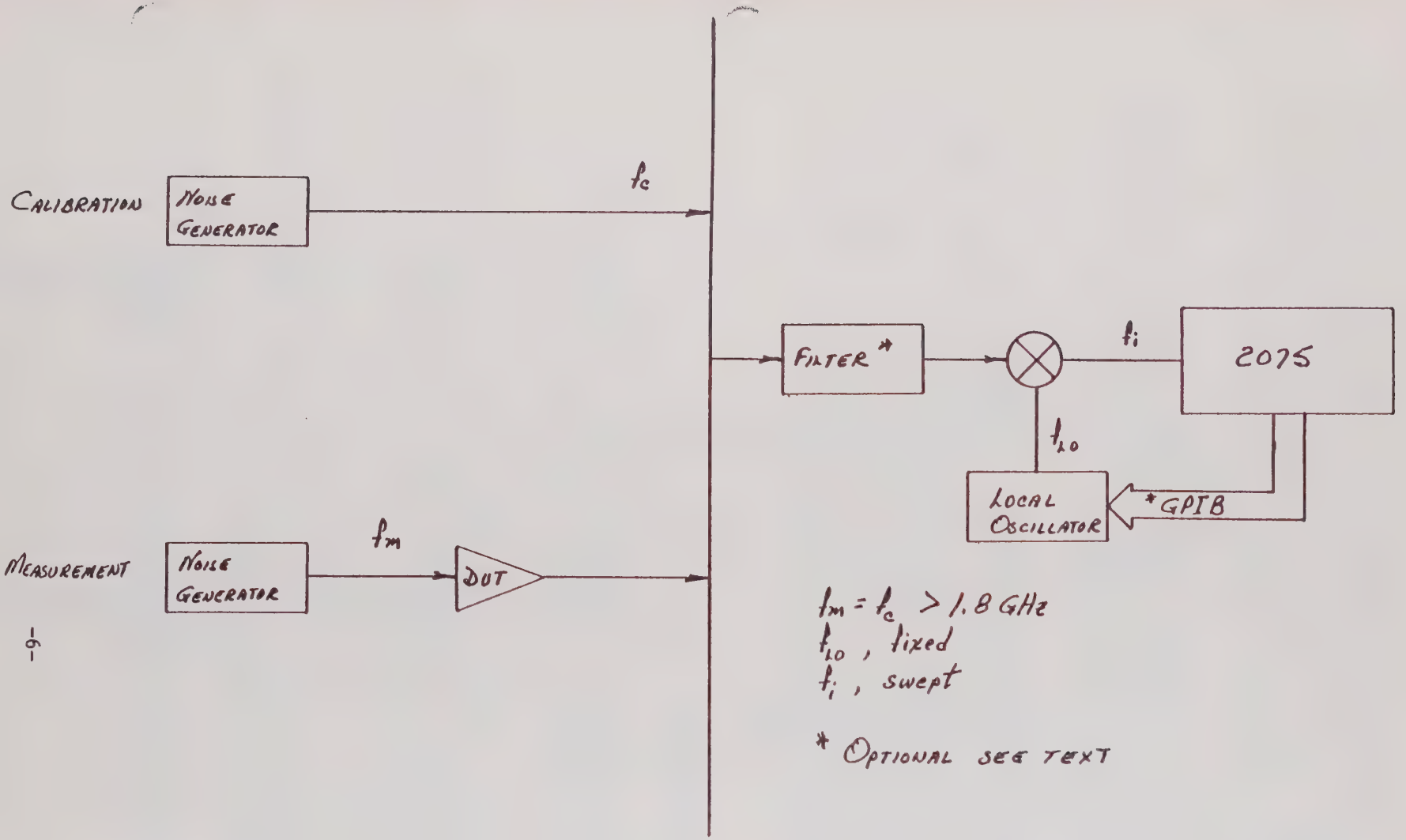
Configuration 1.3

The setup for this mode is similar to 1.2 except that the local oscillator frequency is fixed and the 2075 input frequency is swept. It is referred to as the "fixed L.O., swept I.F." mode.

The primary advantage of this mode is that it does not require an expensive, bus-controllable signal source. The disadvantages are that the sweep width is limited to less than 1800 MHz and double sideband measurements are not available.

The key conditions are similar to 1.2. The calibration and measurement frequencies are equal and greater than 1.8 GHz, and the 2075 input frequencies are less than 1.8 GHz.

The satellite earth station LNA (3.7 to 4.2 GHz) provides a good illustration. The following parameters would be typical.



DUT CONFIGURATION 1.3

For upper sideband operation:

$f_c = f_m$	f_{LO}	f_i	f_{image}
3.7 - 4.2 GHz	2.7 GHz	1 - 1.5 GHz	1.7 - 1.2 GHz

The filter in this case would be a high pass with a cutoff between 1.7 and 3.7 GHz.

For lower sideband operation:

$f_c = f_m$	f_{LO}	f_i	f_{image}
3.7 - 4.2 GHz	5.2 GHz	1.5 - 1.0 GHz	6.7 - 6.2 GHz

The filter would be a low pass with a cutoff between 4.2 and 6.2 GHz.

Note that for lower sideband measurements, the 2075 is swept backwards. This is done automatically by the 2075 when lower sideband is selected in DUT Configuration 1.3.

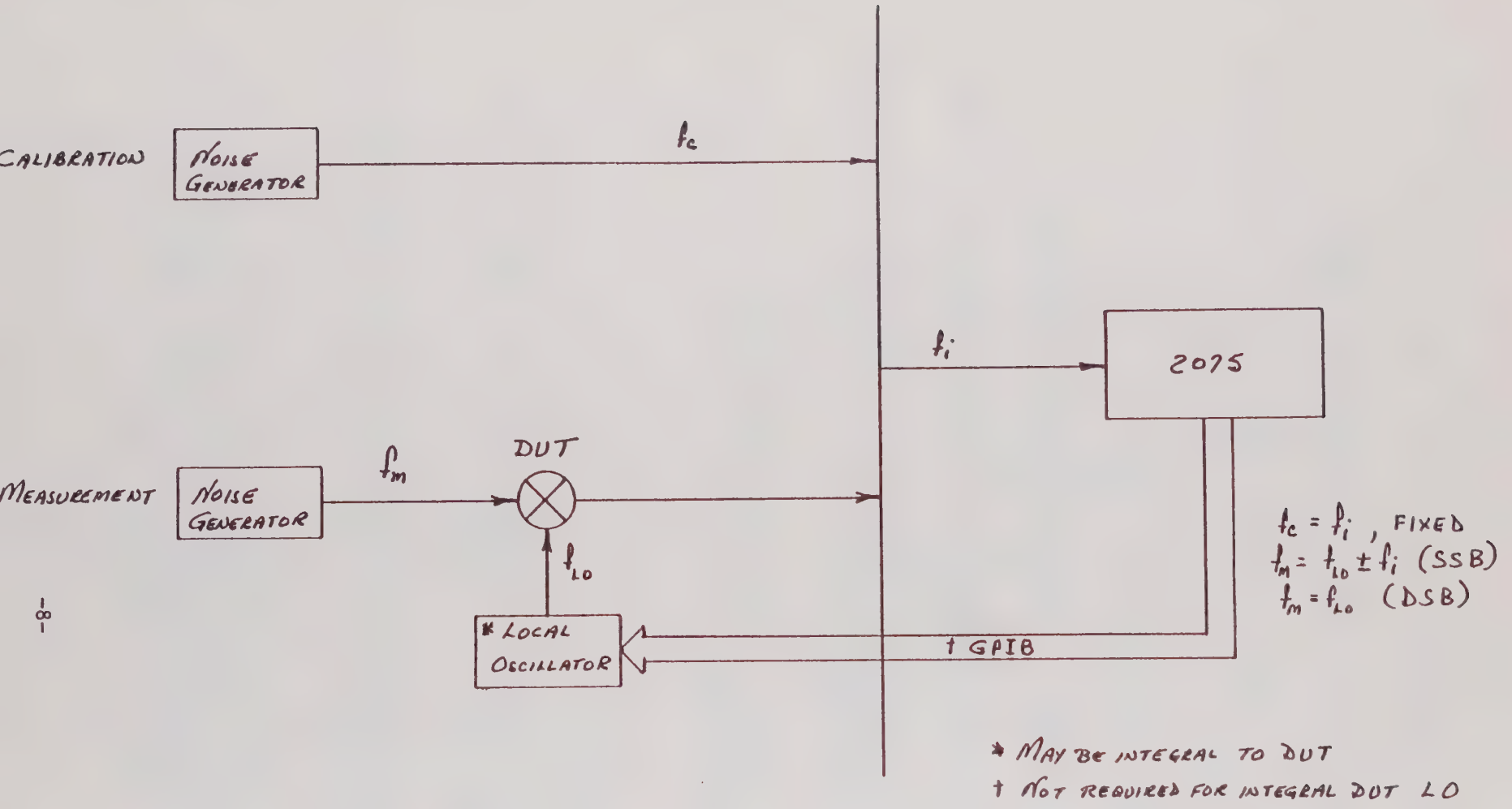
Although the L.O. is fixed, it still may be tuned by the 2075 via the bus control feature.

Configuration 1.4

This configuration would be used to measure a mixer with a specific fixed I.F. output or the tuner assembly of a receiver - such as a television tuner.

The key conditions are that the calibration and 2075 input frequencies are equal and fixed, while the measurement frequencies are different and can cover a range.

When in Configuration 1.4, the 2075 will use the noise generator ENR at the I.F. that is entered for calibration. When the instrument switches to the measurement mode after the calibration is complete, it will use the ENR values for the selected R.F. range.



DUT CONFIGURATION 1.4

Depending upon the sideband selection (upper, lower or double), the 2075 will tune the local oscillator to the appropriate frequencies in accordance with the R.F. and I.F. previously entered.

If no local oscillator is connected to the GPIB output of the 2075, an error message will occur; however, in the case of a tuner measurement (the L.O. is integral to the DUT), this can be ignored.

Configuration 1.5

This configuration offers an alternate method of measuring mixers. In this mode, however, the local oscillator fequency is fixed and the 2075 input frequency is swept.

As with Configuration 1.4, the 2075 will select the I.F. for calibration ENR data and the R.F. for measurement ENR data.

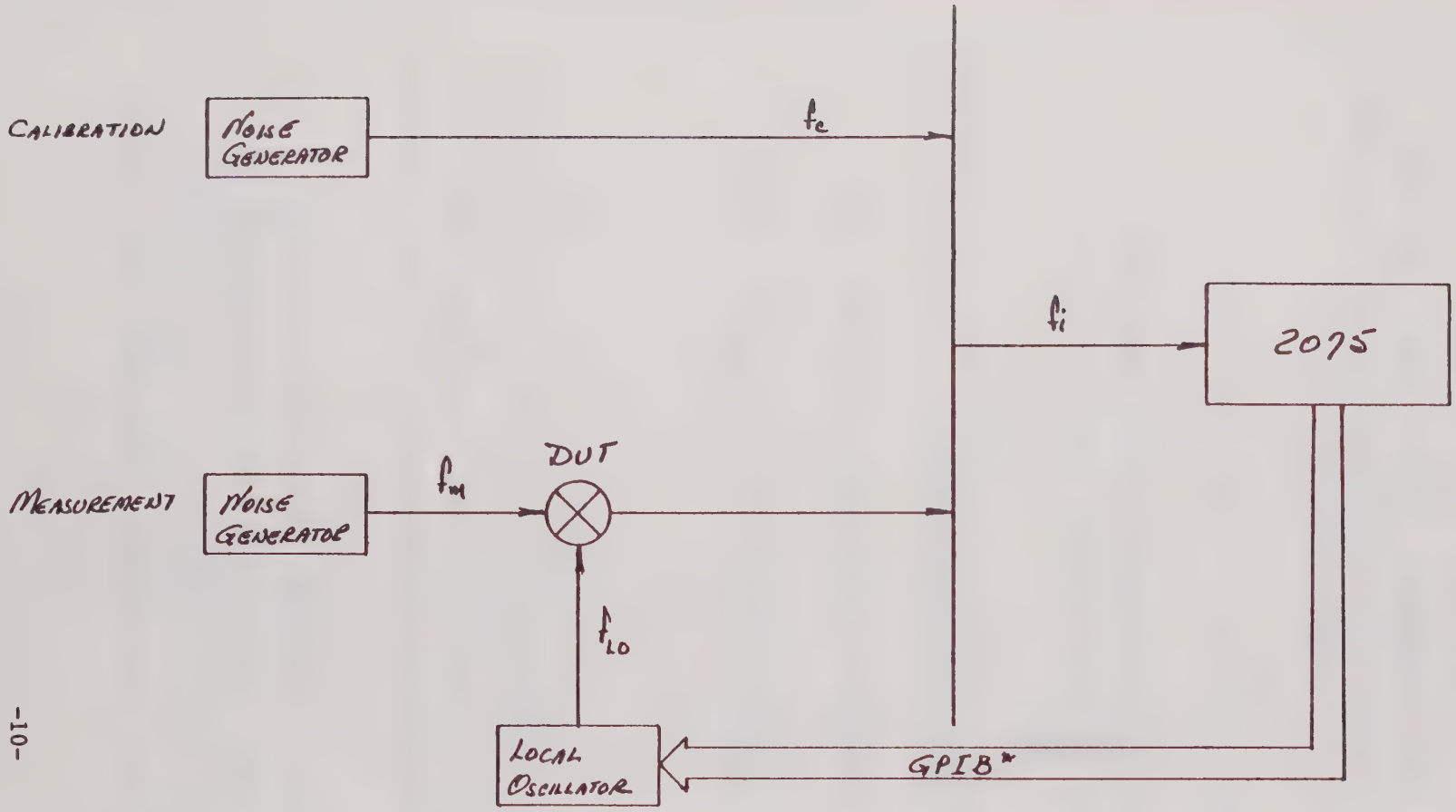
Double sideband measurements are not available in Configuration 1.5

Configuration 1.5 is quite useful for measurement of microwave mixers with broad I.F. responses (typically, D.C. to 1.8 GHz).

Configuration 1.6

This configuration is somewhat of a special case which would be used when it is inconvenient or impractical to use a single downconversion from the measurement frequency to the 2075 input frequency range. It is generally used when the measurement fequency is in the very high microwave region.

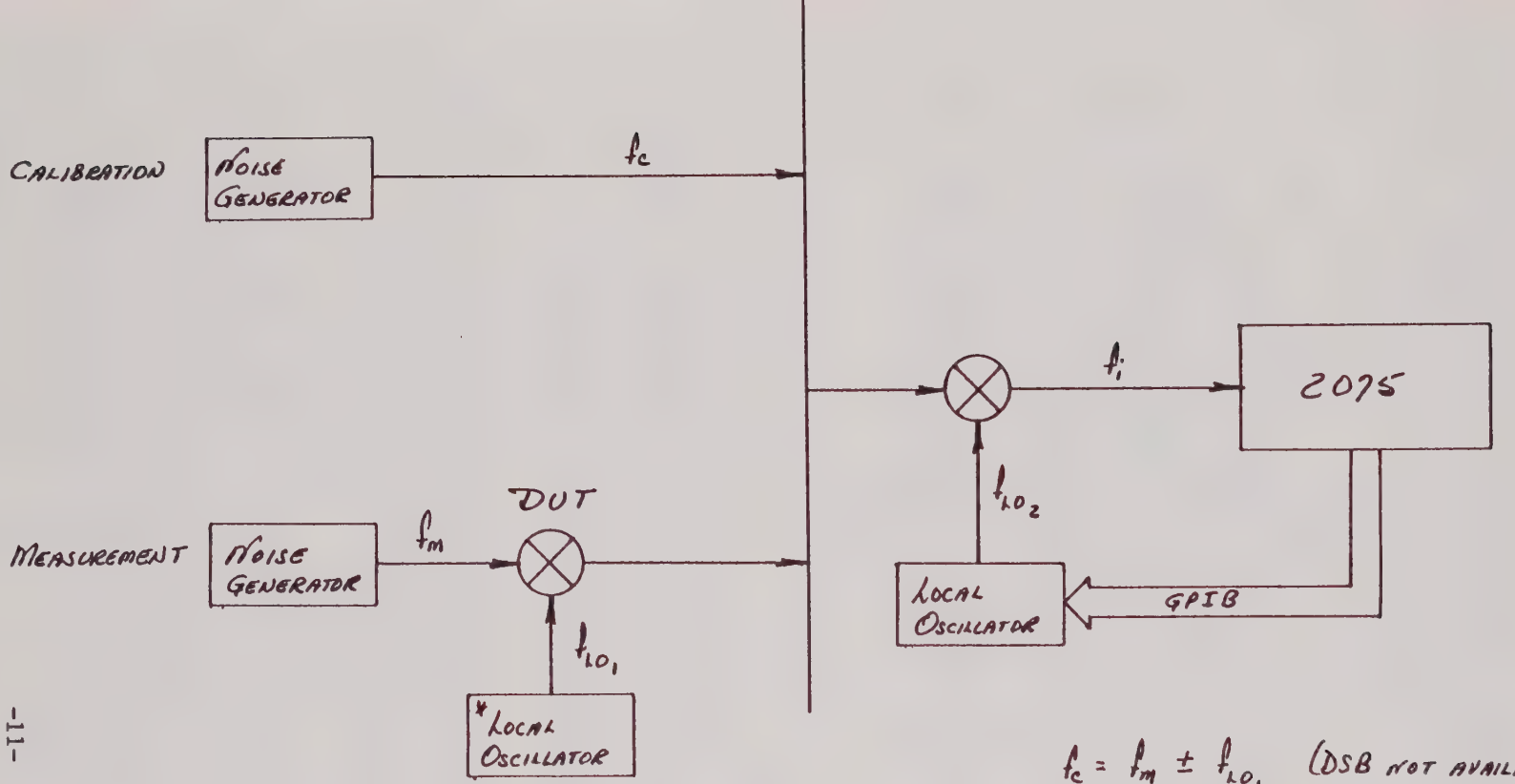
A typical application is measurement of the front-end downconverter of the MILSTAR receivers. The R.F. input range of the converter is 42 to 46 GHz. The local oscillator is integral to the converter and its frequency is fixed at 39 GHz. Thus, the I.F. output ranges from 3 to 7 GHz: obviously, well out of the range of the 2075, and requiring a



$f_c = f_i$, SWEPT
$f_M = f_{LO} \pm f_i$ (DSB NOT AVAILABLE)
f_{LO} FIXED

* OPTIONAL

DUT CONFIGURATION 1.5



*MAY BE INTEGRAL TO DUT

$f_c = f_m \pm f_{LO_1}$ (DSB NOT AVAILABLE)
$f_{LO_2} = f_c$
f_{LO_1} FIXED

DUT CONFIGURATION 1.6

second downcoversion.

As can be seen from the illustration, all three key frequencies - measurement, calibration and 2075 input - are different. Using the MILSTAR receiver to illustrate, a typical set of operating parameters would be:

f_m	f_c	f_{LO2}	f_i
42 - 46 GHz	3 - 7 GHz	3 - 7 GHz	30 MHz

Note that while the upper or lower sideband can be selected for the first downconversion (the 2075 will cause the second local oscillator to sweep backwards if the lower sideband is selected), the calibration (second-stage data) is always double sideband.

Note also that for swept measurements, a bus controllable signal source is required for the second local oscillator. The swept I.F., fixed L.O. mode is not available in this configuration.

III. OPERATIONAL EXAMPLE

The preceeding sections described the various measurement configurations available in the 2075. In this section, we will use a typical measurement as an example of how to set-up the instrument.

For this illustration, we have again chosen our satellite earth station low-noise amplifier (LNA) operating from 3.7 to 4.2 GHz. The example assumes that the appropriate noise generator ENR data has been previously loaded into ENR Table 5.1 in the machine.

Because the measurement will cover only a 500 MHz band, we can make a single sideband measurement. The choice of upper or lower sideband would generally be based on the availability of a suitable local oscillator as would the choice of either the swept I.F. or swept L.O. mode. For this illustration, we have assumed that the only signal source available for use as an L.O. is a manually tuned signal generator operating from 4 to 8 GHz.

The former dictates the swept I.F. mode while the latter dictates a lower single sideband measurement (L.O. frequency higher than the measurement frequency). Typical frequency parameters are given in Section 1.3 and are repeated here for reference.

$f_m = f_c$	f_{LO}	f_i	f_{image}
3.7 - 4.2 GHz	5.2 GHz	1.5 - 1.0 GHz	6.7 - 6.2 GHz

The set-up would be as indicated in Figure 1.3, and the filter, if used, would be a low-pass with a cutoff between 4.2 and 6.2 GHz. As noted earlier, the input fequency of the 2075 is swept backwards for a lower sideband measurement.

In the example given below, Display A, B, C refer to the front panel LED displays entitled FREQUENCY, GAIN and NOISE FIGURE, respectively. Where a "U" appears in a display column below, it means that the information displayed is undefined - the actual display is dependent on previously entered data or operational modes.

Once the step is assembled, the procedure is as follows:

1. Turn the equipment on and allow the 2075 sufficient time to complete its self-test and frequency calibration routines (about 30 seconds).

2. Select noise generator ENR Table 1.

Depress	Display		
	A	B	C
SPEC FUNCT	Sp Fn	0.0	---
5.1	Sp Fn	5.1	---
ENTER	U	U	U

3. Select Swept I.F., Fixed L.O. Configuration

Depress	Display A	B	C
SPEC FUNCT	Sp Fn	0.0	---
1.3	Sp Fn	1.3	---
ENTER	U	U	U

NOTE:

An error message (ERR 123 or 133) may come up at this time. It will return after each entry until all the required parameters are entered. It simply indicates that some of the parameters have not been entered, and it may be ignored.

4. Select Lower Sideband

Depress	Display A	B	C
SPEC FUNCT	Sp Fn	0.0	---
2.1	Sp Fn	2.1	---
ENTER	U	U	U

Again, ERR 133 may be displayed.

5. Select Measurement Frequency Range and Step Size

Depress	Display A	B	C
START FREQ	(Last Start Frequency)	U	U
3700	3700	U	U
ENTER	3700	U	U
STOP FREQ	(Last Stop Frequency)	U	U
4200	4200	U	U
ENTER	4200	U	U
STEP SIZE	(Last Step Size)	---	---
20	20	---	---
ENTER	4200	U	U

6. Select Local Oscillator Frequency

Depress	Display		
	A	B	C
SHIFT	U	U	U
STOP FREQ	(Last L.O. Frequency)	---	---
5200	5200	---	---
ENTER	4200	U	U

7. Set the L.O. frequency to 5.2 GHz and the L.O. output to a level consistent with the mixer requirements.

8. As indicated in Figure 1.3, connect the noise generator to the filter input.

9. Calibrate for second-stage noise correction

   Depress CALIB

   FCAL will appear in the center window indicating a frequency calibration takes place. The 2075 will then step through the input frequency range backwards in 20 MHz increments. The FREQUENCY display will indicate the appropriate R.F. (3.7 to 4.2 GHz). The green light just above the RELAY POWER output jack will be illuminated indicating power is available for operation of external relays.

   The NOISE FIGURE display will indicate second-stage noise figure at each frequency.

   The frequency range will be swept three times each at a different internal attenuator setting indicated in the center (GAIN) display by:

   CAL 1
   CAL 2
   CAL 3

10. At the completion of the third sweep, the 2075 will:

    A. Return to the Start Frequency
    B. Automatically switch to the corrected noise figure plus gain mode (as indicated by illumination of the red indicator on the F+G pushbutton).

    C. Remove the relay power.

    The noise figure and gain displays will vary randomly near 0.

11. Insert the DUT between the noise generator and the filter as indicated in Figure 1.3.

12. Measure DUT noise figure and gain.

    Depress SWEEP.

    The 2075 will step through the selected frequency range measuring noise figure and gain at each frequency. The displayed noise figure is that of the DUT alone (corrected for second-stage noise).

IV. ADDITIONAL NOTES

A. Steps 1 through 7 are setup procedures and need be done only once at the start of the measurement. If many measurements are to be made over a period of several days, the setup can be stored in the front panel memory as follows:

Depress	STORE
	1
	ENTER

The setup configuration is now stored in memory location "1". Since the memory is non-volatile, it will retain the setup indefinitely.

If the setup is not changed, the preceeding storage function is almost superflouous. Each time the 2075 is powered up, it will come up in its last configuration just before power was removed.

B. Steps 8 through 10 are not required each time a measurement is made. The frequency at which the "CALIBRATE" mode is activated is a function of the stability of the external mixer and local oscillator. Typically, it should be done about twice in the first hour of operation and then about once every two hours thereafter.

C. An oscilloscope connected to the rear panel "X", "Y", "Z" BNC outputs on the rear panel can be used to display noise figure and gain versus frequency.

The scope requirements are nominal, and a suitable unit will generally be found in most laboratories. The oscilloscope must have X-Y capability with variable horizontal sensitivity and analog Z-axis modulation (positive voltage for intensification, zero volts blanks the trace).

If the scope is connected before Step 9 in the preceeding procedure, the scope alignment pattern will appear on the screen. This can be used to adjust the vertical and horizontal sensitivity so that the pattern just fills the screen.

If the scope is not connected until after Step 9, the alignment pattern can be obtained by:

Depress	SPEC FUNCT
	7.2
	ENTER

After adjusting the oscilloscope sensitivity, return to the normal measurement mode by:

Depress	SPEC FUNCT
	7.0
	ENTER

When the SWEEP button is depressed in Step 12, the scope will display noise figure and gain versus frequency. Each plot (noise figure and gain) consists of a series of interconnected dots.

The gain plot can be distinguished from noise figure by means of the intensity control on the rear panel of the 2075. This control can be used to make the gain trace slightly fainter than the noise figure trace.

Each dot on the traces represents a measurement frequency. During the sweep, a brighter cursor dot can be seen moving along each trace. This cursor represents the actual measurement frequency at that instant of time. If the sweep is stopped (Depress SWEEP one more time), the measurement frequency represented by the horizontal position of the cursor can be read off the FREQUENCY display. The cursor can then be manually moved across the screen by the fixed frequency increment/decrement pushbuttons for examination of specific regions of the plots in greater detail.

Note that even though the unit sweeps continuously, the display does not change appreciably. This is because the data are digitally stored and the scope is refreshed at a 1 kHz rate.

The oscilloscope scale factors for noise figure and gain can be independently set from the front panel of the 2075. Assume the noise figure of the DUT varies between 1 and 3 dB, and the gain varies between 10 and 30 dB over the frequency range.

Since most oscilloscopes have eight (8) vertical divisions, convenient scale factors would be:

Noise Figure	0.5 dB/div	0 to 4 dB range
Gain	5 dB/div	0 to 40 dB range

To set these limits and scale factors:

Depress	LOWER LIMIT
	0
	ENTER
	UPPER LIMIT
	4
	ENTER
	SHIFT
	LOWER LIMIT
	0
	ENTER
	SHIFT
	UPPER LIMIT
	40
	ENTER

MICROWAVE MEASUREMENTS WITH THE 2075 USING THE SWEPT L.O. MODE

INTRODUCTION

The following is a description of the measurement procedure for a typical microwave application using the swept L.O. amplifier measurement configuration mode.

In this mode, the 2075 acts as a GPIB controller for the local oscillator. The control programs available in the 2075 will drive the following signal source:

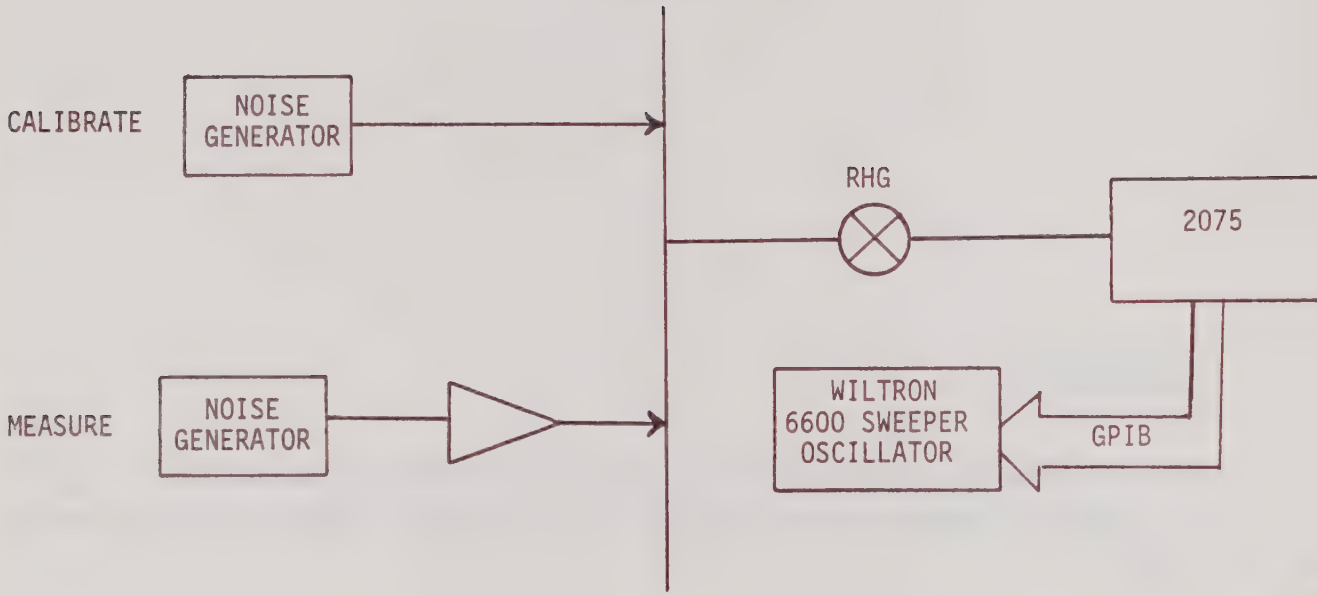
Wiltron 6600
Hewlett Packard 8672
Hewlett Packard 8350

There is also a general programming format available within the unit.

Example

DUT: 4 to 8 GHz amplifier
Measurement Configuration: Swept LO, double sideband
Local Oscillator: Wiltron 6600 series

SETUP



The swept L.O., amplifier measurement configuration requires control of the local oscillator by the 2075 via the GPIB connections.

PRELIMINARY

Before operation in the swept L.O. mode can occur, the bus address of the Wiltron sweeper must be determined. This can be done by powering up the sweeper and depressing the "LOCAL" button in the upper left corner of the sweeper front panel. The bus address should appear in the right-most display window (for this illustration it will be assumed that the Wiltron bus address is decimal "16").

After connecting the equipment as indicated in the illustration (Calibration mode), follow the steps detailed below to set up the measurement configuration. The left hand column describes the required actions. The right hand column details the control manipulation.

ACTION	DEPRESS
Enable amplifier - swept L.O. mode	SPEC FUNCT 1.2 ENTER
Select double sideband	SPEC FUNCT 2.0 ENTER
Enter the sweeper bus address	SHIFT LOCAL 16 ENTER
Select the Wiltron 6600 control program	SPEC FUNCT 47.1 ENTER
Enter the R.F. measurement range and step size for swept measurements	START FREQ 4000 ENTER STOP FREQ 8000 ENTER STEP SIZE 100 ENTER
Select the I.F.	SHIFT START FREQ 10 ENTER

NOTE:

It is desirable to select a low I.F. for double sideband measurements in order to reduce potential errors caused by rapid change of the DUT noise and gain characteristics with frequency; however, at high microwave frequencies, a slightly higher I.F. (e.g., 30 MHz) may be desirable to reduce second stage noise by one or two dB.

ACTION	DEPRESS
Set the L.O. drive to the mixer to +10 dBm (assumed to be the correct drive for this illustration)	SHIFT (Fixed frequency up arrow) 10 ENTER
Enable the controller mode	SPEC FUNCT 40.2 ENTER

At this point, the Wiltron sweeper will shift to the "Remote" mode as indicated by the annunciator at the upper left corner of the sweeper front panel. The output level will go to +10 dBm and it will tune to the last frequency entered on the 2075 (8000 MHz).

The sweeper is now being controlled by the 2075 control program. If the frequency setting of the 2075 is changed, the sweeper will be retuned via bus control to the new setting; e.g., depress START FREQ, and the sweeper should go to 4000 MHz.

SECOND STAGE CALIBRATION

Once the 2075 takes control of the sweeper, a minor change in the operation of the front panel controls will be noted. The 2075 pushbuttons will become "soft". It may be necessary to hold a button depressed for a fractionally longer period of time before the instrument will react.

This occurs because the management processor is being shared by the sweeper control program and cannot accept front panel commands at the same instant of time that it is "talking" to the sweeper.

Before depressing the CALIB button to measure second stage noise, increase the Smoothing until about three segments on the Smoothing indicator are lit. This will significantly increase the length of time required for the three calibration sweeps, and is necessary in order to give the Wiltron sweeper sufficient time to settle at each frequency. In general, the actual measurement sweep may be run faster with less smoothing.

As noted in an earlier technical bulletin describing the first L.O. mode, once the CALIB button is depressed, the 2075 will:

- Do an internal frequency calibration - indicated by the legend FCAL in the center LED window.

- Step through the selected frequency range measuring and storing the second stage noise figure at each frequency. It will sweep the range three times at three different internal attenuator settings indicated by the legends CAL 1, CAL 2, and CAL 3 in the center LED window.

After completion of the calibration sweeps, the 2075 will return to the start frequency (4000 MHz) and automatically switch to the corrected noise figure plus gain measurement mode, indicated by illumination of the LED on the F+G pushbutton.

The GAIN and NOISE FIGURE displays will vary randomly around zero. If the noise figure tries to go below 0 dB while in this condition, the NOISE FIGURE display will be blanked (two dashes will appear in the LED window).

MEASUREMENT

If you wish a swept oscilloscope display of noise figure and gain versus frequency, connect an appropriate oscilloscope to the X, Y, and Z outputs on the rear of the 2075. The oscilloscope requirements are:

- X-Y mode of operation

- Variable sensitivity on both horizontal and vertical axes (the sensitivity settings will be between 0.2 and 0.5 volts/division)

- Positive going Z-axis analog modulation (positive voltage intensities, zero volts blanks)

An alignment pattern is available to assist setting the oscilloscope sensitivity and positioning controls. It can be called up by depressing:

SPEC FUNCT
7.2
ENTER

A less complex alignment pattern is available as Special Funtion 7.1.

Connect the equipment for a measurement as shown in the illustration. Try a sweep at minimum smoothing by depressing the SWEEP button. After at least one full sweep, stop the sweep by depressing the SWEEP button a second time.

Examine the oscilloscope pattern for any unusual characteristics (e.g., an indication of very low noise figure at one frequency). If there are no sudden discontinuities in the noise figure trace, the measurement can be considered valid, and you can continue sweeping and/or taking data.

A rapid change in noise figure at one or more frequencies usually indicates that the sweeper is not being given sufficient time to settle at each frequency, and it may be necessary to increase the dwell time by increasing the smoothing number. This can be determined by tuning the 2075 to the frequency at which the discontinuity occurs and noting whether or not the indicated noise figure changes significantly. This can be done as follows:

Set the fixed frequency increment to the same value as the sweep step size by depressing:

SHIFT
FIXED FREQ
100
ENTER

Use the fixed frequency increment/decrement pushbuttons (up or down arrows) directly under the FIXED FREQ pushbutton to move the bright cursor dot on the oscilloscope display to the frequency

exhibiting to possibly unusual value.

Allow the instrument to dwell at this freuqency and increase the smoothing until about three segments on the Smoothing indicator are illuminated.

If the noise figure indication does not change appreciably (i.e., 0.5 dB or more), the discontinuity is real, and you may continue sweeping and taking data, or you may wish to adjust the DUT to remove the discontinuity.

If the noise figure does change appreciably, it will be necessary to sweep slower by increasing the smoothing number.

CREATING A USER DEFINED EXTERNAL LOCAL OSCILLATOR CONTROL PROGRAM

DESCRIPTION

The 2075 Noise Gain Analyzer provides control programs for several of the popular local oscillators. These are accessed through Special Functions 47.0 through 47.3. The instrument also allows the user to define a custom made control program so that the 2075 can interface with other local oscillators. This feature is provided through Special Function 48.1. After the program has been defined, it can be executed using Special Function 47.4.

The custom program is created by modifying an existing 40 byte "scratch pad" which is part of the unit's RAM area. The user's instructions are entered one byte at a time in decimal form for each of the required ASCII characters. As each byte is entered, it is displayed in the FREQUENCY window on the left side of the front panel.

The ASCII characters and their equivalent decimal forms are given in Table 5-4, US ASCII Character Codes. This table is located at the end of the GPIB section.

PROCEDURE

To create a control program, use the following procedure:

1. To access the "scratch pad" for modification, select Special Function 48.1.

2. The first byte of the "scratch pad" will be displayed on the FREQUENCY window. Key in the decimal value for the desired ASCII character and look at the LED display to verify the entry. If correct, press the ENTER key to store the information. If the value is incorrect, press CLEAR and key in the correct value before pressing the ENTER key.

3. After the ENTER key is pressed, the next byte will be displayed. Repeat the previous step until all of the necessary control program information has been entered. A maximum of forty bytes may be entered, but the program may be terminated at any time by following Step 6.

4. At the point in the program where a frequency parameter should be inserted, enter the decimal value of the ASCII code for CTRL-F. This is a decimal six (6).

5. At the point in the program where a LO amplitude parameter should be inserted, enter the decimal value of the ASCII code for CTRL-A. This is a decimal one (1).

6. When the last control program decimal value has been keyed in and entered, press the ENTER key one more time. The 2075 will return to normal measurement mode.

7. To select the control program, use Special Function 47.4.

8. To execute the control program, use Special Function 40.2.

EXAMPLE

In the following example, assume that a program is required that will control a local oscillator responding to these codes: FQ = fixed frequency, LV = level, MZ = MHz, and DB = dB.

The corresponding ASCII character string and control program decimal values are as follows:

ASCII string	F	Q	CTL-F	M	Z	L	V	CTL-A	D	B
Decimal value	70	81	6	77	90	76	86	1	68	66

Key Sequence 70(E)81(E)6(E)77(E)90(E)76(E)86(E)1(E)68(E)66(E)(E)

where (E) represents the ENTER key.

Using the User defined EXTERNAL Local Oscillator Control program to control an HP 8350 Sweeper.

Follow these steps:

1. Select special Function 48.1

   [SPEC FUNCT] [4] [8] [.] [1] [ENTER]

2. Enter the decimal equivalent of ASCII "C"

   [6] [7] [ENTER]

3. Enter the decimal equivalent of ASCII "W"

   [8] [7] [ENTER]

4. Enter the decimal equivalent of ASCII "CTL-F"

   [6] [ENTER]

5. Enter the decimal equivalent of ASCII "M"

   [7] [7] [ENTER]

6. Enter the decimal equivalent of ASCII "Z"

   [9] [Ø] [ENTER]

7. Enter the decimal equivalent of ASCII "P"

   [8] [Ø] [ENTER]

8. Enter the decimal equivalent of ASCII "L"

   [7] [6] [ENTER]

9. Enter the decimal equivalent of ASCII "Ø"

   [4] [8] [ENTER]

10. Enter the decimal equivalent of ASCII "D"

[6] [8] [ENTER]

11. Enter the decimal equivalent of ASCII "M"

[7] [7] [ENTER]

12. Enter the decimal equivalent of ASCII "A"

[6] [5] [ENTER]

13. Enter the decimal equivalent of ASCII "1"

[4] [9] [ENTER]

14. Enter the decimal equivalent of ASCII "R"

[8] [2] [ENTER]

15. Enter the decimal equivalent of ASCII "F"

[7] [Ø] [ENTER]

16. Enter the decimal equivalent of ASCII "1"

[4] [9] [ENTER]

17. Enter the decimal equivalent of ASCII "M"

[7] [7] [ENTER]

18. Enter the decimal equivalent of ASCII "D"

[6] [8] [ENTER]

19. Enter the decimal equivalent of ASCII "Ø"

[4] [8] [ENTER]

20. End entry sequence

[ENTER]

21. Select user defined program as output program with Special Function 47.4

SPEC FUNCT | 4 | 7 | . | 4 | ENTER

22. Select 2075 as controller with Special Function 40.2

SPEC FUNCT | 4 | Ø | . | 2 | ENTER

- Miniature Noise Generator Serves Measurements from 10 MHz to 26 GHz
- Noise-Gain Analyzer
- Noise and Gain Measurements Simplified by Dual Purpose Instrument

Miniature noise generator serves measurements from 10 MHz to 26 GHz

Noise figure and effective input noise temperature measurements have usually required several separate noise generators to blanket the range of frequencies from 10 MHz to 26 GHz. With the introduction of the model 7626 coaxial RF/microwave noise generator, however, a single miniature device can now perform as the noise source. A typical automated noise measurement setup with the new device is shown in Fig. 1.

The model 7626 exhibits outstanding mismatch performance across its operating range. The VSWR from 12.4 to 26.5 GHz is no higher than 1.20:1, and rises to only 1.25:1 for frequencies from 8 to 12.4 GHz. At the lower end, the performance is even closer to ideal, with VSWRs of less than 1.17:1 from 0.1 to 8 GHz, and less than 1.1:1 for frequencies from 10 to 100 MHz.

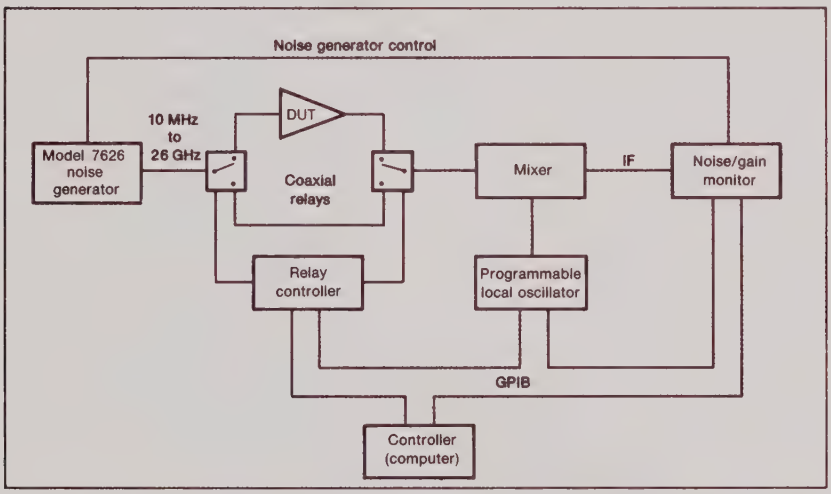
Suspended stripline used

The noise generator was designed using suspended stripline fabrication techniques, as well as a split bias network. The bias configuration eliminates the need for an internal regulator while maintaining excellent thermal stability. One of the consequences of this type of construction is an on/off transition time that typically measures between 1 or 2 μs. As a result, the generator can be employed in short-gate applications, such as synchronous radar noise monitoring.

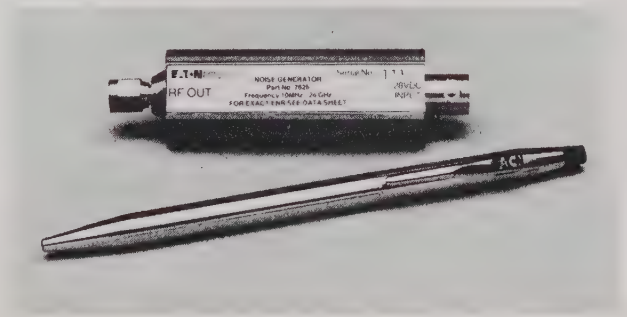
With the exception of a bias resistor, all of the noise generator's circuit elements, including the output attenuator, are assembled on a single substrate that measures only 0.876 × 0.368 cm. This allows the final device to be coaxially packaged (Fig. 2), with an SMA output connector and a BNC female input connector.

The bias resistor is selected during the calibration procedure. As a result, the equivalent noise resistance (ENR) can be kept as linear as possible. At frequencies from 10 MHz to 12.4 GHz, the ENR is 15.4 ± 0.7 dB. From 12.4 to 18 GHz, the ENR is 14.9 ± 1.1 dB, and from 18 to 26.5 GHz, it is 13 ± 3 dB. The 7626 is calibrated for ENR accuracy at specific frequency points, and each noise generator is accompanied by a calibration data sheet. The worst-case ENR accuracy occurs at frequencies from 19 to 26 GHz, where it is ±0.40 dB. At frequencies from 9 to 18 GHz, where the measurement data taken are traceable to the National Bureau of Standards, the calibration uncertainty is only ±0.25 dB.

The broadband nature of the 7626 makes the device suitable for use as a single noise generator for RF and IF noise measurements on the uplink and downlink receivers of a Ku/K-band satellite communication system. The coaxial noise generator operates on a standard +28-VDC line and consumes less than 20 mA current. P&A: 6 wks. **Eaton Corporation, Electronic Instrumentation Div., Los Angeles Operation, 5340 Alla Rd., Los Angeles, CA 90066. (213) 822-3061.** **CIRCLE NO. 156**



1. This test system uses the 7626 broadband noise generator *to make automated noise measurements on units under test (UUT) from 10 MHz to 26 GHz.*



2. The miniature coaxial construction of the 7626 *is owed in part to the use of suspended stripline techniques and a substrate board measuring only 0.876 × 0.368 cm.*

Noise-Gain Analyzer

William E. Pastori, Eaton Corporation
Electronic Instrumentation Div.
Los Angeles, CA

REPRINTED FROM AUGUST 1983 microwave JOURNAL MAGAZINE

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EATON

Noise-Gain Analyzer

Eaton Corp.
Electronic Instrumentation Div.

Eaton Corporation, Electronic Instrumentation Division (EID), has announced the availability of the AILTECH 2075 noise-gain analyzer.

This new instrument can not only measure the classic receiver noise parameter, noise figure, but it can also provide simultaneous gain readout of the device under test in a swept frequency mode from 10 to 1800 MHz, with accuracies of ±0.05 dB for noise figure and ±0.2 dB for gain.

Using two microprocessors and a high-speed A/D converter, the AILTECH 2075 simplifies the typical noise figure measurement and offers significant savings in measurement time by greatly increasing the number of measurements that can be made in a given period of time. It eliminates off-line data corrections for image response effects, second-stage noise and reference temperature deviations from 290°K.

The instrument can be tuned to any frequency in the 10 to 1800 MHz band by front panel pushbutton entry. Start and stop may be similarly entered. In normal operation, the selected frequency increment (step size) can be as small as 1MHz; however, for fine grain observations of noise figure and gain-vs.-frequency, the selected step size can be reduced to 100 kHz for total frequency spans less than 10 MHz. X-Y analog outputs at the rear of the instrument provide for oscilloscope display or X-Y recording of the noise and gain data. A Z-axis output is also provided for blanking or pen lift.

A front-panel SHIFT key permits display of noise performance in terms of effective input noise temperature, rather than noise figure, without having to resort to a "special functions" table. Another useful front panel feature is the dB/ratio pushbutton which permits the operator to express the noise figure and gain results in either form with a single keystroke.

Fig. 1 The Eaton EID AILTECH 2075 noise-gain analyzer.

The AILTECH 2075 is sufficiently sensitive to measure its own noise figure — it can, in fact, measure the noise figure of negative gain devices (mixers, PIN attenuators, etc.) A calibrate routine, activated by a single, front-panel keystroke, causes this measurement to be implemented and the results stored internally over the selected frequency range. When the device-under-test is inserted in the normal measurement setup, the stored results are used to correct the measured noise figure for "second-stage noise," and the corrected values are displayed.

Another time-saving feature is on-line correction of the measured results for cold (reference) temperature deviations from the standard reference temperature, 290°K. Most noise figure measurements are made using a noise generator whose cold, or off, temperature is room temperature. The simplified relation between noise figure and Y-factor, used by earlier instrumentation to provide the noise figure readout, assumes the cold temperature is equal to 290°K. If the assumption is invalid, an error is introduced into the measurement requiring off-line correction of the data.

Because the AILTECH 2075 operates on the raw Y-factor data, the actual cold temperature data can be entered and the displayed results will be automatically corrected for this effect.

The instrument can also act as a controller for two widely-used signal generators over the general purpose interface bus. This feature is useful when measurements must be made at frequencies greater than 1800 MHz and external downconversion is required. The 2075 is capable of controlling two popular, industry-accepted, bus-programmable signal sources. If one of the controllable sources is used as the external local oscillator, the noise-gain analyzer can provide fully-corrected noise and gain measurements in the swept mode without requiring a separate computer and the necessary software. The 2075 can also control a digital printer-plotter.

The accuracy of receiver noise parameter measurements is heavily dependent upon knowledge of the excess noise ratio of the noise generator used and the AILTECH 2075 provides for front-panel entry of up to 93 ENR/frequency data points. The ENR table can be segmented and can, for example, accommodate data for three different noise generators, each with 31 calibration points. The data for a particular noise generator is called up by entering its identification number. The ENR tables are stored in a CMOS memory with battery backup and will remain in memory for up to 72 hours with the power turned off.

The 2075 is fully programmable via the general purpose interface bus (IEEE-STD-488-1978). It measures 5-3/4" x 16-7/8" x 14", requires 5-1/4" panel space in rack mount configuration and weighs about 34 pounds. Full specifications are listed in the table. ■

TABLE 1

AILTECH 2075 SPECIFICATIONS

INPUT	EATON 2075
Frequency Range	10 to 1800 MHz, Tunable
Tuning Accuracy	±(0.5 MHz + 0.005F), ±3 MHz Max
Frequency Resolution	1 MHz (0.1 MHz for $\Delta F < 10$ MHz)
Noise Figure	<7 dB + 0.002 dB/MHz A) P: < −30 dBm
Input SWR	<1.5
Maximum Input Power	0 dBm, Gext 65 dB +25 dBm, Gext 90 dB (NF Measurement Only)
Maximum Net External Gain	65 dB, NF & Gain 90 dB, NF Only
NOISE MEASUREMENT	
Noise Figure Range	0 to 30 dB
Measurement Accuracy	±0.05 dB A) 0 to 12 dB Noise Figure B) +10 to +40°C C) ENR 5 to 18 dB ±0.1 dB A) F>12 dB B) T<$_{10}$°C, >40°C
Resolution	0.01 dB
GAIN MEASUREMENT	
Gain Range	−20 to 65 dB
Measurement Accuracy	±0.2 dB
Resolution	0.01 dB
GENERAL	
Operating Temperature	0 to 55°C
Storage Temperature	−55 to 75°C
Weight	15.5 kg (34 lb.)
Dimensions	5¾" x 10⅞" x 14" (5¼" Rack Panel Space)

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Noise and Gain Measurement Simplified By Dual-Purpose Instrument

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E·A·T·N Advanced Electronics

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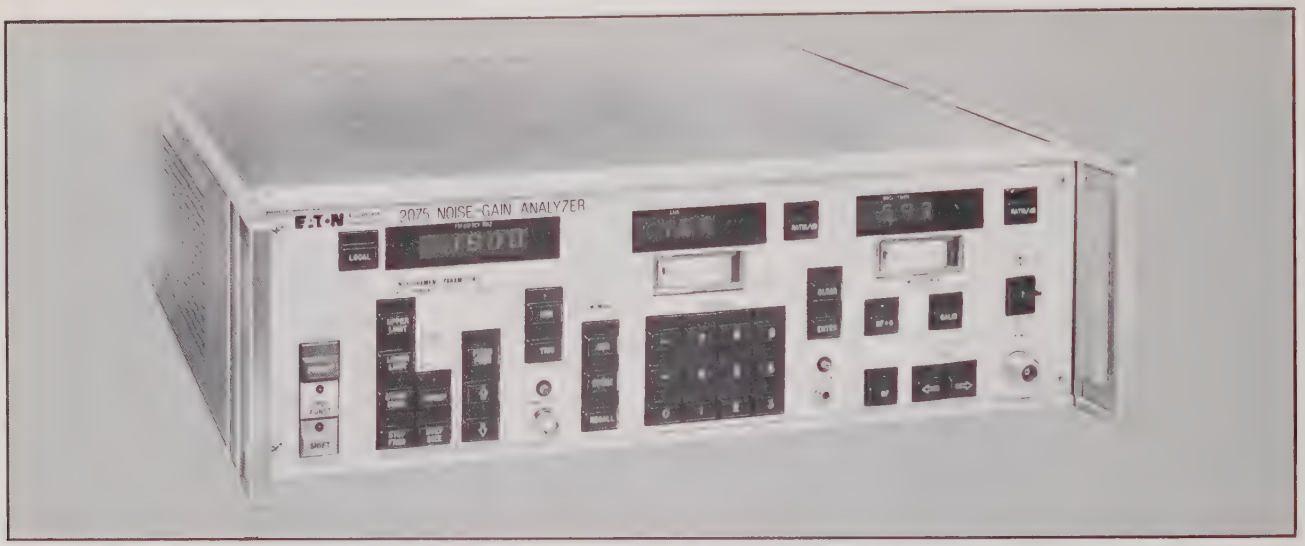
Noise and Gain Measurement Simplified By Dual-Purpose Instrument



1. Noise Figure and gain monitor approaches *combined in a single instrument provide a high-sensitivity, broadband swept capability that is virtually imageless. Model 2075 converts raw noises (Y-factor) data at the output of a highly linear up/down conversion-detection system to digital form with no analog computations. Accuracy is within 0.05 dB at noise figures below 12 dB.*

Model 2075 Noise-Gain Analyzer
Eaton Corp., Electronic Instrumentation Div.
2070 Fifth Ave.
Ronkonkoma, NY 11779
(516) 588-3600

Microprocessor-based and computer compatible, Model 2075 noise-gain analyzer measures not only the noise figure, but also provides simultaneous gain readout of the device under test in a swept-frequency mode from 10 to 1800 MHz with accuracies of ±0.05 dB for noise figure, ±0.2 dB for gain.

Using two microprocessors and a high-speed A/D converter, the instrument simplifies the typical noise-figure measurement and saves measurement time by greatly increasing the number of measurements that can be made in a given time period. Thus, it eliminates the off-line data corrections necessary with earlier instrumentation such as image-response effects, second-stage noise, and reference-temperature deviations from 290K.

The 2075 can be tuned to any frequency in the 10- to 1800-MHz band by front-panel bush-button entry. Setting start and stop frequencies, and step size for swept frequency measurements, is equally simple. In normal operation, the selected frequency increment (step size) can be as small as 1 MHz; however, for fine grain observations of noise figure and gain vs. frequency, the selected step size can be reduced to 100 kHz for total frequency spans less than 10 MHz. X-Y analog outputs at the rear of the instrument provide for oscilloscope display or X-Y recording of the noise and gain data. A Z-axis output is also provided for blanking or pen lift.

A front-panel SHIFT key permits display of noise performance in terms of effective input noise temperature, rather than noise figure, without needing a special functions table. Another useful front-panel feature is the dB/ratio push button, which permits the operator to express the noise figure and gain results in either form with a single keystroke.

Model 2075 is sufficiently sensitive to measure its own noise figure. It can, in fact, measure the noise figure of negative-gain devices such as mixers and PIN attenuators. A calibrate routine, activated by a single, front-panel keystroke, causes this measurement to be implemented and the results

Model 2075 Noise-Gain Analyzer

FUNCTIONS & FEATURES	
Noise Figure Display	FdB F YdB* Y* Te (K) M* *Requires SP function. All others are front panel control. Return from SP function is front panel control. dB/Ratio selection for F or Y is from a panel toggle.
Display Control	Default display is FdB
Controller Functions	8672A 8350A Printer-Plotter General Format
ENR Storage Capacity	3 sets at 31 frequencies 1 ROM input (4 total)
Analog Display Setup	F & G min-max, front panel
External Relay Drive	5, 15 or 30 V, operator selected by internal jumper

NOISE MEASUREMENT

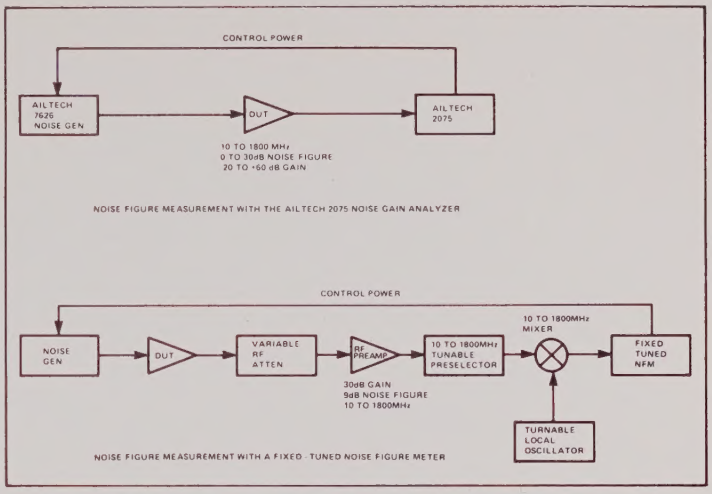
Noise Figure Range	0 to 30 dB
Measurement Accuracy	±0.05 dB a) 0 to 12 dB noise figure b) +10 to +40°C c) ENR 5 to 18 dB ±0.1 dB a) F >12 dB b) T < 10°C, >40°C
Resolution	0.01 dB

GAIN MEASUREMENT

Gain Range	−20 to 65 dB
Measurement Accuracy	±0.2 dB
Resolution	0.01 dB

GENERAL

Noise Source Drive	+28.0 +0.05 V, 100 mA avg On >1 V OFF
Operating Temperature	0 to 55°C
Storage Temperature	−55 to 75°C
Power	100, 120, 220 or 240 V (±10%) 48–66 Hz; 150 VA max.
Weight	15.5 kg (34 lb.)
Dimensions	5¾" x 16⅞" x 14" (5¼" rack panel space)



***2. Setup for noise-figure measurement** is considerably simplified with the new noise-gain analyzer (top) as compared to a fixed-tuned noise figure meter (above).*

SUPPLEMENTAL

Bandwidth	5 MHz (nominal)
Measurement Speed	6 to 10 meas/sec
Maximum safe input level	±20 VDC; +25 dBm RF

to be stored internally over the selected frequency range. When the device under test is inserted in the normal measurement setup, the stored results are used to correct the measured noise figure for "second-stage noise," and the corrected values are displayed. This feature can save considerable off-line data reduction, or in the case of computer-automated measurements, hours of software generation and debugging.

Another time-saving feature is on-line correction of the measured results for cold (reference) temperature deviations from the standard reference temperature, 290K. Most noise-figure measurements are made using a noise generator whose cold, or off, temperature is room temperature. The simplified relation between noise figure and Y-factor, used by earlier instrumentation to provide the noise-figure readout, assumes the cold temperature is equal to 290K. If the assumption is invalid, an error is introduced into the measurement requiring off-line correction of the data.

Because the 2075 operates on the raw Y-factor data, the operator can enter the actual cold temperature, and the displayed results will be automatically corrected for this effect.

The instrument can also act as a controller over the GPIB. This feature becomes extremely useful when measurements must be made at frequencies greater than 1800 MHz. Such meaurements require the use of an external downconversion scheme. The 2075 is capable of controlling two popular, industry-accepted, bus-programmable signal sources. If one of these sources is used as the external LO, the noise-gain analyzer can provide fully corrected noise and gain measurements in the swept mode without requiring a computer and the necessary software generation.

A digital printer-plotter can also be controlled by the 2075; thus, this feature can also provide hard-copy display of the measurement results.

The accuracy of receiver noise parameter measurements is heavily dependent upon knowledge of the output (excess noise ratio, or ENR) of the noise generator used to stimulate the device under test. The 2075 provides for front-panel entry of up to 93 ENR/frequency data points. The ENR data table can be segmented according to the number of calibration points provided with the noise generator. For example, the instrument can accommodate data for three different noise generators, each with 31 calibration points. The data for a particular noise generator can be called up by entering an identification number; the instrument can be set up so that it is not restricted to use with a single noise generator. The ENR data tables are stored in a CMOS memory with battery backup; thus, the data will remain in memory for up to 72 hours with the power turned off.

The instrument is fully programmable via the IEEE-488 bus, and is therefore suited to both laboratory and systems applications. ■

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